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ABSTRACT

This technical paper offers an alternative method to the traditional physical geography course which has as its primary objective the knowing of approved body of knowledge. The premise is that a discipline of physical geography does not now exist and that traditional physical geography consists of nearly independent topics treated without common process or methodology. The suggested alternative interface system, defined as the study of the workings of the environment at the interface at the bottom of the atmosphere, focuses on the role of location or "place" in the different work accomplishments of environment and upon work allocation and budgeting. The unifying focus of this alternative is the timing (and, eventually, the amounts) of these work accomplishments -- energy flows and conversions--by systems which share the energy and material endowments of the interface, where man's enterprises are found. Physical systems and society's dependence and effects on them are both included in the alternative. In conclusion, it is suggested that the proposed alternative to physical geography could provide the basis for a unifying discipline if a significant number of physical geographers report work accomplishments of environmental systems. (Author/SJM)

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# THE INTERFACE AS A WORKING ENVIRONMENT: A PURPOSE FOR PHYSICAL GEOGRAPHY

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# THE INTERFACE AS A WORKING ENVIRONMENT:

# A PURPOSE FOR PHYSICAL GEOGRAPHY

*by*

Douglas B. Carter
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## FOREWORD

The Technical Papers are explanatory manuals for the use of both instructors and students. They are expository presentations of available information on each subject designed to encourage innovation in teaching methods and materials. These Technical Papers are developed, printed, and distributed by the Commission on College Geography under the auspices of the Association of American Geographers with National Science Foundation support. The ideas presented in these papers do not necessarily imply endorsement by the AAG. Single copies are mailed free of charge to all AAG members.

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Many of the better established ideas in this paper are well known in the work of the late C. Warren Thornthwaite. The ideas of many others have also been basic to our thinking. Nevertheless, we have not provided many references since this is not a review of the state of the art but an exercise in logic and persuasion.

We express our appreciation to the following for the encouragement and stimulation they gave: E. B. Espenshade, Jr., John F. Lounsbury, J. Ross Mackay, and those who have met with the Panel on Physical Geography of the CCG since 1969: M. G. Marcus, J. M. Goodman, H. A. Winters, M. G. Wolman, J. N. Rayner, T. R. Detwyler, and Ian Manners. Much is owed to Nicholas Helburn and Gilbert White for an earlier example in curriculum improvement. Our chairman, Frank Thomas, has been a constant source of encouragement. Also, interaction with many unidentified students has been crucial to developing the convictions expressed and the positions taken in this paper.

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# CHAPTER I

## INTRODUCTION

We propose to define physical geography as a study of the workings of the environment at the interface at the bottom of the atmosphere.[1] This focus gives emphasis to the role of location or "place" in the different accomplishments of environments. It is suggested that such a physical geography could make a unique contribution to the Earth Sciences by analyzing the power of environments from the workings of physical processes in the surface region where man's enterprises are found. Effective penetration of questions of man's use and strategies for environment also should be facilitated by this view of physical geography.

While it is evident that essentially the same subtopics must be treated in the proposed alternative as the traditional course contains, the main changes are concerned with models of when and how work is done in systems of the local environment. A principal advantage of our alternative is that all the parts of the subject can be unified by one analytical methodology and paradigm. Importantly, the alternative raises major questions of how some systems work which are as yet unanswered and which we believe would be an invitation to students of the need for a continuing application of their intellect and imagination. By contrast, we believe the traditional view of physical geography (as it is exemplified by the available textbooks) is clearly a federation of nearly independent topics treated without any process or methodology in common for all its parts. That an alternative to the traditional physical geography is urgently needed must be appreciated.

It is no accident that physical geography was the first to have a panel of the Commission on College Geography to deal with the needs of a particular subfield of geography. An eloquent plea by Merle Prunty to the Council of the AAG in 1968 for "something" to be done about the beginning course was the precipitating event for the formation of the Panel on Physical Geography. Repeatedly, the panel dealt with questions of whether the main problems of the field were procedural or organic. We hold that the main questions are organic and that an alternative conception of physical geography is needed; an addendum will not suffice.

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[1] This plane nearly coincides with "the home of man" concept which has wide acceptance in geography. Also, it is nearly "the biosphere" or "the environment," concepts of some currency. Obviously, we do not intend only the two-dimensional plane of "the" interface; we recognize a third dimension as described by Miller (see David H. Miller, The Heat and Water Budget of the Earth's Surface, in *Advances in Geophysics*, Vol. 11, 1965, p. 180). Furthermore, it is convenient on occasion to regard "the" interface as the outer surface of the lithosphere; this ambivalence is similar usage to "surface of the earth."

Our procedure in this paper consists of three main steps. First, the need for an alternative physical geography is made apparent from an examination of several of the supposed merits claimed for the present course. Second, an alternative is proposed having as its unifying focus the timing (and, eventually, the amounts) of work accomplished by systems which share the energy and material endowments of "the" interface at the bottom of the atmosphere. Our purpose is to shift the subject from a focus on *things* of environment to one of explaining when and how environmental work is allocated among various systems. Third, we offer examples of the pervasiveness of this approach to the context of geography—both the geography concerned solely with physical systems and that which deals with society's dependence and effects on them.

## CHAPTER II

# WHAT SHOULD PHYSICAL GEOGRAPHY ACHIEVE?

Physical geography is widely credited with certain unique attributes for the educational experiences of students. Often it is claimed that physical geography is a presentation of earth science; similarly, the claim is made that physical geography integrates a number of natural science or environmental sciences; the most unique claim for physical geography probably is that it presents the distributional dimension of environment so students would have an acquaintance with the factual qualities of places. Another important function which is claimed for physical geography relates to the service which the course provides as a foundation for other studies in geography departments; thus, physical geography often is a required course for majors and it must be taken before certain other sequences. These merits probably ought to be preserved by any alternative conception of the physical geography course. But, improvement of our educational effect should be sought so we need some criteria that could be used to evaluate any course and could serve to indicate what other merits physical geography ought to attain.

### Criteria for Evaluating a Physical Geography Course

Evaluation of any course, much less a division of a field, is difficult, complex, and lacking in any agreed criteria.[2] We have selected three criteria for evaluation which seem to constitute an essential minimum. We submit that in order for a course to be healthy, it must have: (1) a clear unifying internal theme and methodology to provide a common focus or framework for displaying the integrity of questions and issues that concern it; (2) a functional relation with the rest of the discipline and the questions it addresses in order to demonstrate that it is an interdependent part of the professional enterprise; and (3) a pedagogic approach that directs the learner toward new questions and fosters self-motivated learning through inquiry into unknowns, in contrast to an emphasis on inculcating traditionally accepted facts and principles of the discipline. We consider these criteria to be a yardstick by which to evaluate any course, not only a means to illuminate the strengths and deficiencies of the physical geography course. Accordingly, we invoke these criteria for assessing merits and needed changes in the present physical geography course as well as for an alternative physical geography which this paper introduces.

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[2] Hastings, J. Thomas, et al., *Evaluating Geography Courses,* Technical Paper No. 3, Commission on College Geography, Association of American Geographers, Washington, D.C. (1970) p. 1.

**What is Cohesive About Physical Geography?**

The theme of a course ought to indicate what cohesive purposes justify its parts and help to make the subject manageable by suggesting what is and what is not reasonably included. Some of the themes which have been employed for physical geography are so all-inclusive that it is difficult to imagine what can be excluded. For example, one theme variously states that physical geography presents earth science or that it integrates a number of natural sciences. We believe this approach leads to an encyclopedic content for physical geography and a loss of identity among the sciences as to the contribution of physical geography, aside from its organizational role. Also, it is not understandable to other sciences what expertise inherently lies in physical geography for integrating or organizing. If we wish to claim as our theme the integrating role, it would be appropriate to consider what has been gained by this approach. Although it is claimed that physical geography integrates the major variables at the earth's surface as part of a broader context of physical environment, it is apparent that there seems to be some confusion between integration and the scope of topics included. Even casual inspection of the texts and syllabi of physical geography indicates no sense of whole environments resulting from integrating synthesis can be detected. Each borrowed subject such as landforms, climate, etc., is treated with its own taxonomy and classification which, in fact, does more toward encouraging separation than integration. Little attention is given to fitting the separate subjects together as components of an environmental system or some other larger earth system. How can there be a unifying scheme common to such diverse objectives as genetic classification for landforms and soils, regional descriptive classifications for climate and vegetation, and assorted other treatments for water and oceans?

Further, it is widely held that physical geography stresses the spatial patterns of physical phenomena thus filling a void left by the earth sciences. There may be some validity in such a statement; however, the presentation of a map to display the distribution of a particular physical phenomenon without the development of definitive skills of analysis does not constitute so great an improvement in understanding as to warrant a separate discipline of physical geography.

It is with respect to a theme that physical geography is most in need of an alternative formulation. We propose that the work of the interface is a theme which could embrace parts of virtually all the topics of traditional physical geography, could identify us among other sciences as having a special expertise, would focus on how work is done rather than the things of environment, and would be quite pertinent to problems of the remainder of the field of geography.

**What Should Physical Geography Have to Do With the Rest of Geography?**

Geographers often consider physical geography as the requisite treatment of the physical environment for students. The question then becomes, is physical geography, as normally presented, a treatment that can be interrelated effectively with the rest of the field of geography?

The traditional emphasis of physical geography, like the earth sciences, is

particularly directed toward understanding the genesis of physical systems. The elements of description and classification are logically those most diagnostic with regard to genesis and genetic processes. If such a focus for physical geography were to provide an effective connection to the rest of the field of geography, the remainder of the field would have to have genetic and descriptive interests also. For the rest of geography, the physical environment is not a system to be understood for its own sake. Presumably the components of environment that have greatest importance to all of geography are those defined by the values of the human systems which relate to seasonal and dynamic dimensions in the complex of man in environment. It is to be expected, therefore, that geography as a social science may not, and does not, find a physical geography that focuses on genetic classifications or genetically oriented treatments (traditional to most physical geography texts) to be particularly adapted to its needs.[3] For example, a geomorphological treatment of the landforms and a pedological treatment of the soil for a particular place are not directly related to an understanding of the land resource base for agricultural decisions concerning that place. Properties of surface configuration and agronomic properties of soils, on the other hand, would be of greater relevance because they can be directly related in an evaluation of given practices of agricultural systems, but such properties may not be considered important in a geomorphological or pedological treatment. The apparent conclusion is that these treatments in physical geography do not relate well at all to the holism of geography, and, in fact may preclude likely discovery of truly operational relationships between the physical environment and man's involvement with it.

Another poignant commentary on the contemporary role of physical geography as a part of geography is that the profession, at least in the United States, has had difficulty demonstrating what, if any, function there is for physical geography beyond its introduction.[4] Pain has been taken especially in the presence of students to assert the unity of geography, yet there is scant evidence that professionals take this idea seriously. For example, one sees many geography departments with little or no physical geography. In others it may be offered only at an introductory level and then often as a service course for physical science credit only. Its content seems not to be demanded beyond this level in geography programs. As a prerequisite to any of the specialties (climate, geomorphology, etc.,) a course in physical geography is so diffuse that the pertinent materials are generally reviewed at a later time or presented anew. It seems safe to assert that most physical geography courses, but especially the introductory ones, demonstrate little, if any, relevance in

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[3] A similar conclusion seems implied by Chorley. R. J. Chorley, "A Re-evaluation of the Geomorphic System of W. M. Davis," in *Frontiers of Geographical Teaching*, R. J. Chorley and Peter Haggett, Ed., Methuen and Co., Ltd. (London, 1965), pp. 35–36.

[4] See: John Leighly, "What Has Happened to Physical Geography?", *Annals of the A.A.G.*, Vol. 45 (Dec., 1955), pp. 309–318; Frank Ahnert, "Some Reflections of the Place and Nature of Physical Geography in America," *The Professional Geographer*, Vol. 14 (Jan., 1962), pp. 1–7; J. D. Chapman, "A Consideration of the Relations of Geomorphology and Geography," *The Professional Geographer*, Vol. 15 (March, 1963), pp. 13–17; and B. J. Garnier, "A Program for Physical Geography," *The Professional Geographer*, Vol. 15 (July, 1963), pp. 16–19.

content or context to the rest of the field, and that the student in physical geography learns little that the geographic profession finds fundamental and essential.

Revitalization of physical geography as a contributing, integral part of the field demands an alternative to what now exists. Of prime importance for such an alternative should be a view where physical geography attends to those qualities and configurations of the physical environment that are strongly interwoven into the maintenance of humanity. The obvious points of emphasis are the uses man makes of the physical environment to sustain life and satisfy his other needs and desires. However, it must also be recognized that use by man modifies the environment. Thus, the working environment is dynamic in its own right, but in the presence of man its work is modified by his utilization and manipulation of environment. The position of mankind with respect to the physical environment is within its dynamic, working context. Man is not ruled by environmental systems but is dependent upon them, cannot avoid affecting them, and is forced to manage himself and the physical environment and/or to endure the inexorable consequences.

**What is the Intellectual Challenge of Physical Geography?**

In far too many courses, the pedagogic challenge for the instructor and the learning challenge for the student are largely comprised of knowing current terminology and concepts. "Knowing" rather than "learning how to learn" has been the prevailing nature of the challenge not only in physical geography but in a variety of courses.

If learning to learn were to become the pedagogic challenge of physical geography, the course necessarily would have to stress those concepts which are pertinent for problems of the present and the future. Learning to learn would require the Socratic ethic of welcoming responsible challenge to the reasoning of its concepts and schemes and giving attention to the possible merits of alternatives to the established, accepted truths.

If, on the other hand, the main objective of physical geography remains the knowing of an approved body of knowledge, the conduct of the physical geography course must be rather different from that described above. Knowing is facilitated by representing knowledge in the most authoritative fashion. Expediting the knowing task requires orthodoxy of explanation and guiding the reasoning by neophytes to approved conclusions.

What are the challenges in the present physical geography? Development of the vocabulary of physical geography, which so frequently consists only of a term and a definition, is most prominent. Endlessly, the language accumulates and there seem to be almost no non-genetic problems which demand such ruffles and flourishes as cirques, zastrugis, moraines, and cuspate forelands. What purpose then exists for this language? Can it be used to reason about some problem of the present or future?

Second, we have made goals of the classifications which evolved originally in the

course of examinations of problems. Classifications now are used to derive spatial distributions rather than the reverse. While the original objectives and logic of classifications were directed to functional relations among climate, soils, and vegetation, it is now presumed widely that classifications need no particular improvement and one could serve to identify regions which would be more or less coincident with the others. The presumption of authority in our classifications seems to be both a misplaced trust and a deterrent to inquiry—even regarding old problems, let alone the present or future.

Finally, there is a preoccupation with representing the status of process by the "average," "natural," or presumed steady state, especially in an annual context in present physical geography. The seasonal or episodic variation in process seems nearly lost from physical geography. Yet, it is those effects of the erratic events which make the disproportionate changes in other systems. Present physical geography seems to have an inadequate conception of physical processes. Processes are not merely associated with the state of systems in an area; physical processes are prescribed relations by which a definite quantity in one system enters into and participates in the functioning of another system for a real time. Moreover, the duration and intensity of those relationships are quite variable and are subjected to interruptions. For those questions about the physical environment which now plague mankind, the timing of process events in both the short run and the long run is the factor to which management strategies consistently are attuned. Unfortunately, a posture of "knowing" is essentially antithetical to process elucidation and simulation. Maps and classifications of putatively representative states of physical conditions merely tabulate "something" for memorization. Without an understanding of the dynamics of processes, especially of their timing, a large spectrum of questions of great interest to society and to managers of certain land or other resources is largely precluded from students of physical geography courses.

The traditional structure of knowledge in physical geography does little to equip the student to use the acquired knowledge beyond the course as a means for continually opening new opportunities for him to learn and understand the working environment better. In a very real sense, the approach of most introductory physical geography seems to stress the need to "qualify" or to be proficient with selected artifacts of past learning rather than to develop skills in evaluating the operation of environmental systems.

## The Task for an Alternative Physical Geography

To improve upon the traditional physical geography requires an alternative conception which would meet the criteria set forth earlier in a better fashion.

1. The traditional course, as exemplified in basic texts, clearly does not go far enough toward integrating the components of the subject. An alternative should emphasize whatever is distinctive about physical geography. We propose that a focus on the work of the interface region can improve these attributes for physical geography.

2. A knowledge of traditional physical geography does not mesh well with geography as a whole. The dominance of genesis or simple distribution which underpins much physical geography discourse and its knowledge goals ignores the fundamental importance of how men use and interact with the working environment from which they must sustain themselves. The intellectual goals of understanding genesis and simple distribution appear at best tangential to furthering geographical understanding of the man-environmental system. We believe that an alternative view of physical geography which deals with the work of the interface systems is a direct input into other geographic questions concerning man's use and management of environment. Such a focus can lead easily to the mutually beneficial dialogue that should be expected within the discipline of geography between those more concerned with matters of physical environments and those more concerned with human systems.
3. An alternative physical geography ought to make more important contributions to problem-solving and to learning how to reason more about the working environment than traditional physical geography has provided. The objective of "knowing" an authorized body of material has turned attention inward away from problems shared with other sciences and has not led to an identification for physical geography as a regularly contributing discipline among other sciences. An alternative physical geography must not exhibit a lack of contemporary problems nor a lack of enough common purpose with other sciences in existing problems. To do so might prevent students from appreciating the challenge of geography, and especially of physical geography, as a coherent, distinctive one.

The obvious question at this point is, what positive alternatives are there for a course in physical geography that might meet the criteria set forth earlier? In different words, what might the physical geographer offer which could provide a conceptual framework for generating stimulating and exciting questions about environment, could lead to understanding how the physical environment itself works, and might be functionally useful in geography as a whole? In the remainder of this paper, we attempt to formulate such an alternative and inquire whether it can measure up to the evaluating criteria presented above.

CHAPTER III

# CONTEMPORARY OPERATION OF THE INTERFACE ENVIRONMENT: A FOCUS FOR PHYSICAL GEOGRAPHY

We propose an alternative physical geography, defined as the study of the working of the interface environment. This definition makes the interface region not merely a locator for what concerns us but a vehicle to differentiate our interest from earth science or other surveys of environment which claim the vast dimensions of space, the atmosphere, the depths of the oceans, and the lithosphere. It should be emphasized that we do not propose to inventory the interface environment; the objective is to study the *working* of the surface environment. This approach not only unifies the subject around main ideas of how much and when work is accomplished, which the traditional study of objects in environment seems not to do very well, it also provides a prod to consider what we need to know. Moreover, the consistent focus on work and its timing stipulates the requirement for a methodology of investigation of when any work is constrained and when it has various intensities relative to other kinds of work in environment. In this section, we outline the central ideas by which an alternative physical geography might address the tasks specified in its definition.

## The Interface Environment

We choose the interface not as an object of study but as a convenience for reviewing the processes of environment and their timing. The interface is the only place where all major natural systems impinge on one another; it is the place which is the recipient of energy and material inputs imposed externally; it is the place where water is partitioned into two dissimilarly acting forms; it is the plane where allocations of energy and moisture are negotiated among systems. Thus, the interface serves as the accountant's bench for natural systems. Importantly, it is also the region where man's connections to environment are made.

The two main endowments onto the interface are radiant solar energy and precipitation. They accomplish rapidly a great deal of visible work. The circulation of energy and moisture endowments to and from the interface constitute the energy budget and the moisture budget of the earth as climatologists know them. Since the water budget cannot be separated effectively from the energy budget, one implies the existence of the other. This dual economy of energy and moisture is the main dynamic ingredient of such greatly overlapping concepts as climate, the hydrologic cycle, environment, or ecosystems. We are constrained by the definition we gave above to deal only with the interface aspects of energy and moisture cycling.

The set of processes which operates from beneath the interface may appear to be independent of those which operate from above it, but there is a great deal of exchange between them. The rock cycle has been proposed as a continuity focused on the solid rock materials. The rock cycle traces numerous paths for interface materials to become transported, or relocated beneath the interface, and to become chemically and physically altered by the energy, density, and pressure conditions of subsurface environments. We restrict our interest to the rock cycle's endowments of material and motion at its interface with the ocean and atmosphere. This restraint is imposed in the interest of enhancing the coherence of our subject matter and methodology.

**Systems in the Interface Environment**

The study of the interface environment might proceed taxonomically to identify and list all the rich detail of things produced by the circulation of energy and water as well as of rock materials. But, that would separate the workings of environment from the things produced. Moreover, the timing of work in environment would not be examined explicitly by that approach, and a main connection to human use of the earth would be neglected. We propose to focus on the systems of the working environment in order that the timing of work in systems might give a comprehensive view of the environmental dynamics and rhythms of work which may be compared with the timing of achievements in human systems.

The main systems which are identified traditionally in physical geography are the atmospheric, biologic, hydrologic, pedologic, and geomorphic systems. These systems, themselves, are impotent. They only do work according to the timing and amount of energy and material allocated to them and stored in them. The focus of our interest is not in the systems of the interface, taxonomically, but it must be on the schemes of allocation for energy and materials which determine relative amounts and timing of work in the interface environment systems.

*Energy in Interface Environment Systems*

The energy which does work in systems is a tiny portion of the total energy endowment of a place. Preponderantly, the radiant energy endowment is converted to heat at the interface and then radiated anew in invisible form to the atmosphere and to space. The atmosphere absorbs most of this kind of radiation and, in turn, recycles energy many times as new radiations back and forth to the interface before it escapes to space. Thus, the main achievement of solar radiation is repetitious heat storage in the atmosphere with invisible radiation providing the continual transfers. The second most important destiny for solar energy, quantitatively, is for that vaporization of water and circulating of the atmosphere which constitutes the force for the hydrologic cycle.

The access of energy to the work of most systems in environment is governed by the presence of water. Water acts as an "energy gate" in some cases, providing the means for the ambient energy to be effective in processes such as soil chemistry reactions. Water also can act as a forcing function, transmitting kinetic energy in

erosional activities. When water is inadequately available in environment, most environmental processes are curtailed although certain work of the atmosphere tends then to be accentuated.

*Water in Interface Systems*

In general, the water occurring on the land is derived directly from the precipitation endowment. Important exceptions to this generalization (such as water bodies, swamps, etc.,) do exist and must be treated as special cases. Quantitatively, the precipitation endowment is allocated mostly to the capillary water form which sticks to solid surfaces in thin films. Capillary water can't fall off the particles, so it is removed mainly by plant roots and passes through plants to the atmosphere with only a trivial retention by plants for growth. Some capillary water also is vaporized directly as evaporation. Evapotranspiration expresses the two processes which vaporize water to the atmosphere and is the opposite of rainfall in environment.

Water from below the root zone, even though saturation may be present only several feet below, does not move rapidly enough to replace significantly the capillary films taken by plants from the root zone soil. Capillary water is replenished almost entirely by infiltrating rainfall. The actual evapotranspiration (AE) of any period is also defined in practice as the capillary water extraction, ignoring the tiny amounts delivered to photosynthesis.

In the interface region, precipitation is allocated to capillary film storage as a high-priority item. Unless the precipitation rate is so intense or the condition of the substrate is such that little moisture can infiltrate, the precipitation received is available for replenishing capillary storages.

Precipitation endowments of a place may also be allocated to gravity water, the liquid water which saturates the voids among particles or runs over the surface to streams. The gravity water which percolates through the root zone to be added to ground water subsequently flows to streams. It is derived from precipitation (at most places) but only when capillary water has been replenished to the soil root zone. Also, a part of the precipitation endowment may be too intense for the prevailing infiltration conditions into the soil so an overland flow of gravity water to stream channels may then occur. Recent evidence indicates overland flows may be a rather small quantity of total precipitation.[5]

An enormous mass of ground water lies beneath the level of streams, so it is a "deposit." Each addition by gravity water percolation to the deposit creates a tendency for water to discharge to streams as base flow. Overland flow during storms and the delayed base flow between storms together are derived from the water which is surplus to the needs for replenishing capillary storages. This water surplus (S) identifies all gravity water produced from precipitation over a long period of time, such as a year. In a long period, streams acquire both the overland flow and the percolating water which seasonally increments the ground water

[5] Whipkey, R. Z., "Subsurface Stormflow From Forested Slopes," *Bulletin of the International Association of Scientific Hydrology*, Vol. 10 (1965) pp. 74–85.

deposit. Except for some unrepresentative, but real, areas where ground water discharges directly to the sea or where sizeable areas of swamps or lakes evaporate gravity water directly to the atmosphere, water surplus must total to the same quantity as streamflow in the long run.

**Work in Interface Systems**

Work is the result of energy flows and conversions from one form of energy to another. In order to model the allocation of energy to the various systems and to the many forms of energy, we need many more measurements than are presently available and we shall have to learn whether there are priority arrangements for energy in environmental systems. Unfortunately, we are only on the threshold of measurements of energy in environmental systems. Many measurements are needed if the absolute amounts of work in environments and the efficiencies of energy use by processes in systems are ever to be understood. It is of no great importance that we can measure the total energy in environment if the part of it which is ever available for work is a greatly varying but largely unknown proportion of the endowment. The allocation of energy among systems and forms is the ultimately desirable measure though it is not yet available; nevertheless, a great insight into the timing of work in environment is available from observing water's various roles as constant companion to the portion of energy which is effective for work in systems.

The work in chemical and primary biologic systems of the interface appears to be completely dependent upon the simultaneous availability of ambient energy and capillary water. Water, especially in the capillary form, comprises an energy gate by which the energy endowment can become effective in interface systems. When capillary water is absent, energy is impotent; but for energy to be most freely effective in chemical and primary biologic processes, it appears that a maximum of capillary water must be present. For kinetic energy to be most effective, a maximum of moving gravity water is needed. Thus, as a first approximation or working hypothesis, the timing of work in the interface seems to be capable of prediction by accounting separately for capillary and non-capillary water as an indication of the timing of the relative energies and work associated with each.

*Gravity Water as a Measure of Work in Environmental Systems*

Where the work of interface systems is due to moving gravity water, the forcing function energy is transmitted by the water itself. When gravity water moves or exerts a force, its "head" or potential energy is dependent upon elevation differences. Other features of environment also may enter as efficiency factors governing work by gravity water. Yet, both the timing and relative amount of work in systems clearly depend upon the regime and amounts of gravity water because the moving gravity water transmits the forcing function for work. In the hydrologic system, gravity water is the only input to ground water. Although there is a need to improve our ability to estimate short-term allocation of gravity water to ground water increments and to streamflow, an accurate estimate of water surplus would seem to be a complete estimate of the long-term mobile water of the hydrologic

cycle on land. Gravity water occurrence is seemingly of little positive, direct importance for the main biologic phenomena. In the soil system, gravity water frequency affects heat conductivity and the storage of heat. Its frequency is a principal determinant also of the cohesiveness of soil under mechanical stress such as the traction exerted by moving men, animals, or vehicles. As a leaching agent, water surplus rinses soils of the materials dissolved in its capillary films.

Geomorphic systems are greatly dependent upon the presence of gravity water. Mass wasting processes concerned with the failure of slopes in sediments are notably seasonal and are claimed by soil physicists to be instigated by pore water pressures and/or pressures exerted by freezing. It is likely there may be a direct proportionality between the probabilities of geomorphic events and the amounts of gravity water or water surplus at various seasons. An estimate of streamflow could provide an extremely interesting tool for studying the energy available for local and regional transport (and deposition) of sediments. Seasonal effects of streams, ice, ground water, even the wind, can be elucidated by the timing of the allocation of precipitation at the interface to the capillary and gravity water which provide the matrix and the driving force for weathering, cohesion, and transport.

*Capillary Water as a Measure of Work in Environmental Systems*

Unlike gravity water, capillary water films do not act as a forcing function to make changes in systems because of their inherent energy relations. While gravity water exerts a kinetic and potential energy, capillary water acts only as a medium.

The status, or contemporary amount, of capillary water is a conditioning factor in such events as frost heaving, heat transfer and storage in soils, cohesion of mechanically disturbed soils or wind attacked sediments, and the environmental aridity of micro-organisms in soil and litter. Estimating the amount of capillary water can be a guide to the probability of work in any of these circumstances.

The energy which sustains the flow of capillary water through plants to the atmosphere, as transpiration, maintains other functions of the plant (including photosynthesis and growth) in proportion to the transpiration stream. Although it is not a forcing function for growth, AE is apparently proportional to the water (presumably also the energy) employed for photosynthesis since the latter is asserted to be proportional to transpiration.

Capillary water removal in a period of time is a useful surrogate of ambient energy available for chemical processes. Chemical weathering, decomposition of organic materials, and possibly also the respiration of plants are each chemical processes regulated by many factors, yet they appear to be driven by thermal conditions only in the presence of capillary films. Accordingly, AE accounts an increase in its own value and in associated processes during seasons with rising temperatures, provided soil moisture is available and is replenished adequately. During periods of highest temperatures, AE often could be much greater but moisture is not available adequately so AE and activities which share the ambient energy as well as the available capillary water are curtailed because there is a moisture deficiency. The potential usefulness of AE as a surrogate, or empirical

correlate, of chemical and organic processes which are regulated by both heat and capillary moisture availability is evident. The need for measures of evapotranspiration, capillary, and gravity water is great but they are rarely provided by meteorological services. Nearly always they must be estimated, empirically, from some paradigm which allocates precipitation according to reasoned choices.

**A Paradigm for Estimating the Allocation of Precipitation Endowments Among the Forms of Water Associated with Different Kinds of Work in Systems**

Estimating the allocation of water to capillary and non-capillary destinies requires a paradigm for consistent decisions about the seasonally changing partitioning of precipitation among those choices. This requirement may be served by some kind of water budget. Water budget techniques achieve an accounting of moisture as a bookkeeping procedure from precipitation measures and empirically estimated values of potential moisture loss and capillary storage capacity. In a water budget procedure, the potential evapotranspiration (PE) of water which available energy could cause if there were no shortage of moisture is considered to be a *demand* for water while precipitation is considered a *supply*. Capillary soil moisture storage capacity is nearly always so inadequately measured that a capacity must be deduced or assumed for most problems. There are unresolved questions of how best to estimate potential evapotranspiration, infiltration, soil moisture storage capacity, soil moisture withdrawal rates and runoff, but some sort of water budget is probably always preferable to none.

*General Rules for an Allocation Model or Water Budget*

Although there are several alternative procedures for estimating parameters of the water budget, the computation of a water budget by whatever method of estimating potential evapotranspiration and whatever assumptions about soil moisture characteristics always takes the following general forms. For daily, weekly or monthly periods, while precipitation is greater than potential evapotranspiration, first priority is accorded to evapotranspiration losses. Actual evapotranspiration (AE) is then equal to potential evapotranspiration (PE) so water increments to capillary storage could be made also during this wetting period until the capillary capacity (ST) of the soil is surfeited. In the event that the soil's capillary capacity is reached, excesses not lost to actual evapotranspiration nor added to storage in the soil are credited as water surplus (S).[6] For periods when precipitation is less than potential evapotranspiration, moisture must be accounted as withdrawn from capillary soil moisture storage (but usually not from ground water). Water deficit (D) results when actual evapotranspiration, the moisture accounted as truly available for evapotranspiration, falls short of the potential evapotranspiration because capillary storage cannot supply enough to meet demands.

[6] The further partitioning of water surplus between quantities immediately delivered to streams and the portion for seasonal disposition as percolating increments to ground water, then base flow, is an option for hydrologic studies.

These cryptic rules of the water budget analysis are hardly sufficient for every circumstance. For example, no single value of capillary storage could be regarded as universal. A *great deal* of work is needed to improve our ability to estimate more precisely and more widely all features of the water budget. While this requirement is especially pertinent for questions that are affected by the water budget of large areas, it is usually possible for studies of a particular location to measure some factors such as infiltration and/or net radiation and then to check or to estimate by sophisticated empirical means the remaining features of the local water budget. Investigators are obligated to take into consideration local conditions which make the water budget different from general models. In these ways, we may obtain estimates of AE and ST (capillary storage) or the components of water surplus which may take into account the specific restraints of problems we wish to investigate.

*Two Sample Water Budgets*

Water budgets for Cloverdale, California and Manhattan, Kansas, two places where budgets are familiar through the literature,[7] illustrate great seasonal contrasts in the regimes of the energy and moisture endowments. Tables 1 and 2 show the accounting ledger for each station, and Figures 1 and 2 portray graphically the progression through the year of the water budget elements.

A brief description of the water budget will be offered here. Those interested in a more detailed discussion of water budgeting techniques will find a rich literature.[8]

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[7] Major, Jack, "A Climatic Index to Vascular Plant Activity," *Ecology*, Vol. 44, (1963), pp. 485–498; C. W. Thornthwaite, "An Approach Toward a Rational Classification of Climate," *Geog. Rev.*, Vol. 38, (1948), pp. 55–94.

[8] Carter, Douglas B. (ed)., *Fresh Water Resources*, High School Geography Project, A.A.G., (1966); Jen Hu Chang, *Climate and Agriculture*, Chicago, Aldine Press, (1968); C. W. Thornthwaite and R. J. Mather, *The Water Balance*, Pub. in Clim., Vol. 8, No. 1, Drexel Institute of Technology, (1955).

Table 1

Water Budget Accounting Ledger
for Cloverdale, California, (millimeters)

| | J | F | M | A | M | J | J | A | S | O | N | D | Yr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 20 | 27 | 40 | 57 | 80 | 109 | 126 | 113 | 89 | 63 | 34 | 20 | 778 |
| P | 250 | 173 | 137 | 58 | 32 | 9 | 1 | 1 | 19 | 38 | 109 | 177 | 1004 |
| P–PE | 230 | 146 | 97 | 1 | –48 | –100 | –125 | –112 | –70 | –25 | 75 | 157 | |
| ΔST | 0 | 0 | 0 | 0 | –48 | –52 | 0 | 0 | 0 | 0 | 75 | 25 | |
| ST | 100 | 100 | 100 | 100 | 52 | 0 | 0 | 0 | 0 | 0 | 75 | 100 | |
| AE | 20 | 27 | 40 | 57 | 80 | 61 | 1 | 1 | 19 | 38 | 34 | 20 | 398 |
| D | 0 | 0 | 0 | 0 | 0 | 48 | 125 | 112 | 70 | 25 | 0 | 0 | 380 |
| S | 230 | 146 | 97 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 132 | 606 |

Table 2

Water Budget Accounting Ledger
for Manhattan, Kansas, (millimeters)

| | J | F | M | A | M | J | J | A | S | O | N | D | Yr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PE | 0 | 0 | 19 | 51 | 93 | 139 | 164 | 150 | 101 | 52 | 14 | 0 | 783 |
| P | 20 | 30 | 38 | 71 | 110 | 117 | 115 | 95 | 86 | 58 | 38 | 22 | 800 |
| P–PE | 20 | 30 | 19 | 20 | 17 | –22 | –49 | –55 | –15 | 6 | 24 | 22 | |
| ΔST | 20 | 24 | 0 | 0 | 0 | –22 | –49 | –29 | 0 | 6 | 24 | 22 | |
| ST | 72 | 100 | 100 | 100 | 100 | 78 | 29 | 0 | 0 | 6 | 30 | 52 | |
| AE | 0 | 0 | 19 | 51 | 93 | 139 | 164 | 124 | 86 | 52 | 14 | 0 | 742 |
| D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26 | 15 | 0 | 0 | 0 | 41 |
| S | 0 | 2 | 19 | 20 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 58 |

There is little difference in the energy endowments at Cloverdale and Manhattan, as indicated by 778 mm. vs 783 mm. of potential evapotranspiration (PE), respectively. With regard to the precipitation endowment, Manhattan receives 20 percent less in its annual total (800 mm.) than Cloverdale (1004 mm.). In spite of this, the ostensibly drier place–Manhattan–has an actual evapotranspiration (AE) that approaches PE, while Cloverdale has an AE that is barely one-half PE. The remainder between PE and AE, the moisture demand that cannot be satisfied, represents a sizeable moisture deficiency at Cloverdale (380 mm.). At Manhattan there is a more complete utilization of the energy resources which is indicated by a smaller deficit (41 mm.). On the other hand, Cloverdale generates over 600 mm. of surplus for streamflow, far in excess of the expected 226 mm. that represents the surplus of annual precipitation over annual PE (1004 mm. vs 778 mm.). Manhattan generates a negligible quantity by comparison, 58 mm., although its precipitation is only 200 mm. less than that of Cloverdale. The two water budgets show some striking contrasts that result from the seasonally contrasting magnitudes of energy and moisture endowments.

This series of perplexities which cannot be resolved with annual values of energy and moisture endowments becomes more manageable when the seasonality of these endowments is considered. The graphs show clearly one aspect of the reason for the values presented above; the tables show another. Looking at the trend of PE and precipitation in Figures 1 and 2, we see that precipitation and PE both undergo seasonal variation at each place. PE is high in midyear and low in the early and late months at both places. The seasonal variation of precipitation doesn't necessarily follow that of PE. PE and precipitation undergo seasonal variation in phase at Manhattan, but they are six months out of phase at Cloverdale. The endowment of moisture is high when the demand for moisture is high at Manhattan, but not at Cloverdale. The limited ability of soil to receive and store moisture is a further consideration. We have assumed that the soil at each place can store 100 mm. of capillary moisture and subsequently make it available for evapotranspiration. If

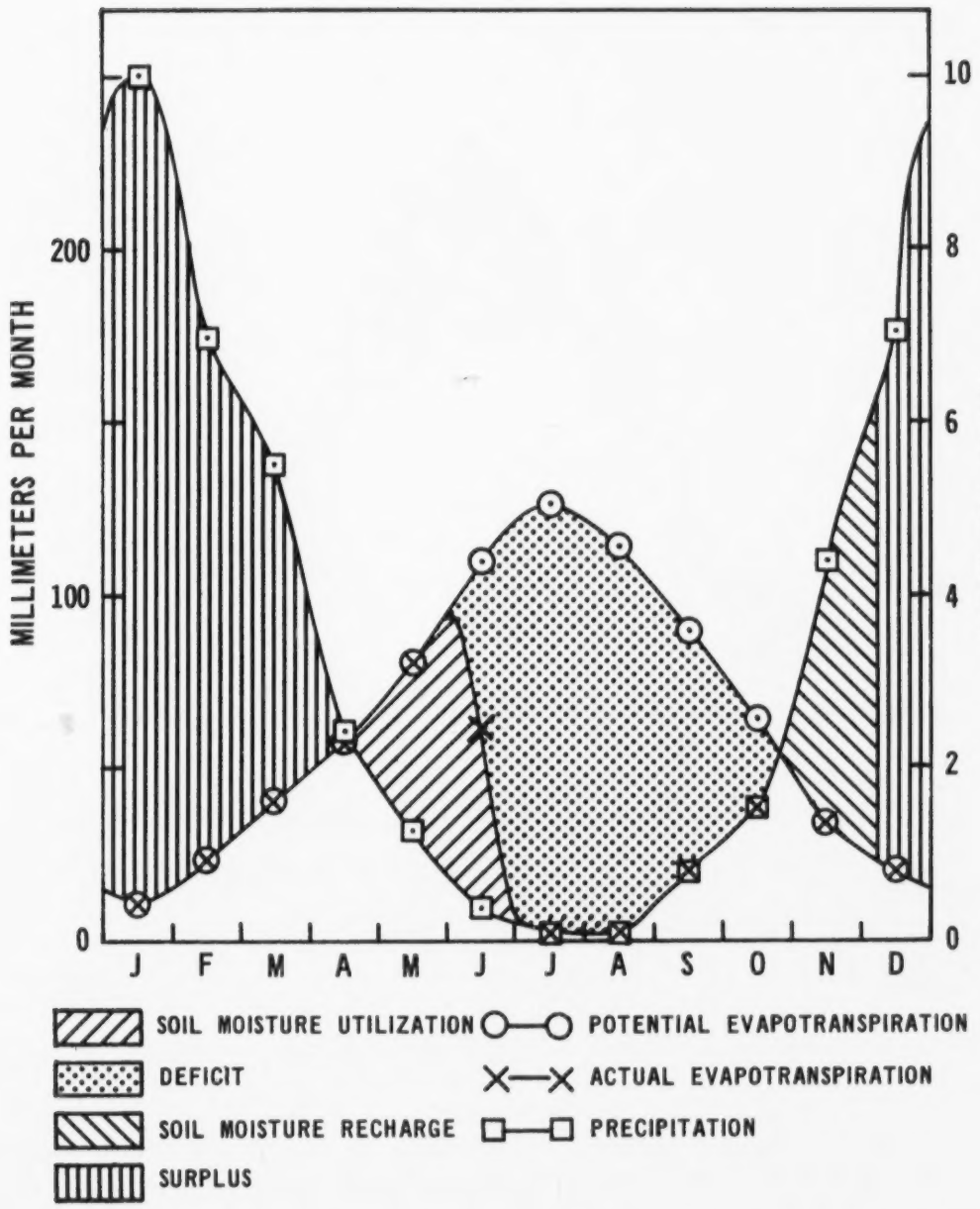


Figure 1 Average Monthly Water Budget for Cloverdale, California (millimeters)

precipitation exceeds PE by more than this amount over a period of consecutive months, the moisture-holding capacity of the soil will be overwhelmed, and a surplus generated. In the accounting ledgers, Tables 1 and 2, soil moisture storage is shown as increasing to 100 mm., and then a surplus is generated. At Cloverdale, the precipitation exceeds PE during November to April by 706 mm., producing a surplus of 606 mm. A similar calculation for Manhattan shows that precipitation exceeds PE during October through May by 158 mm. to produce 58 mm. of surplus. The stored 100 mm. of moisture is then released by the soil for

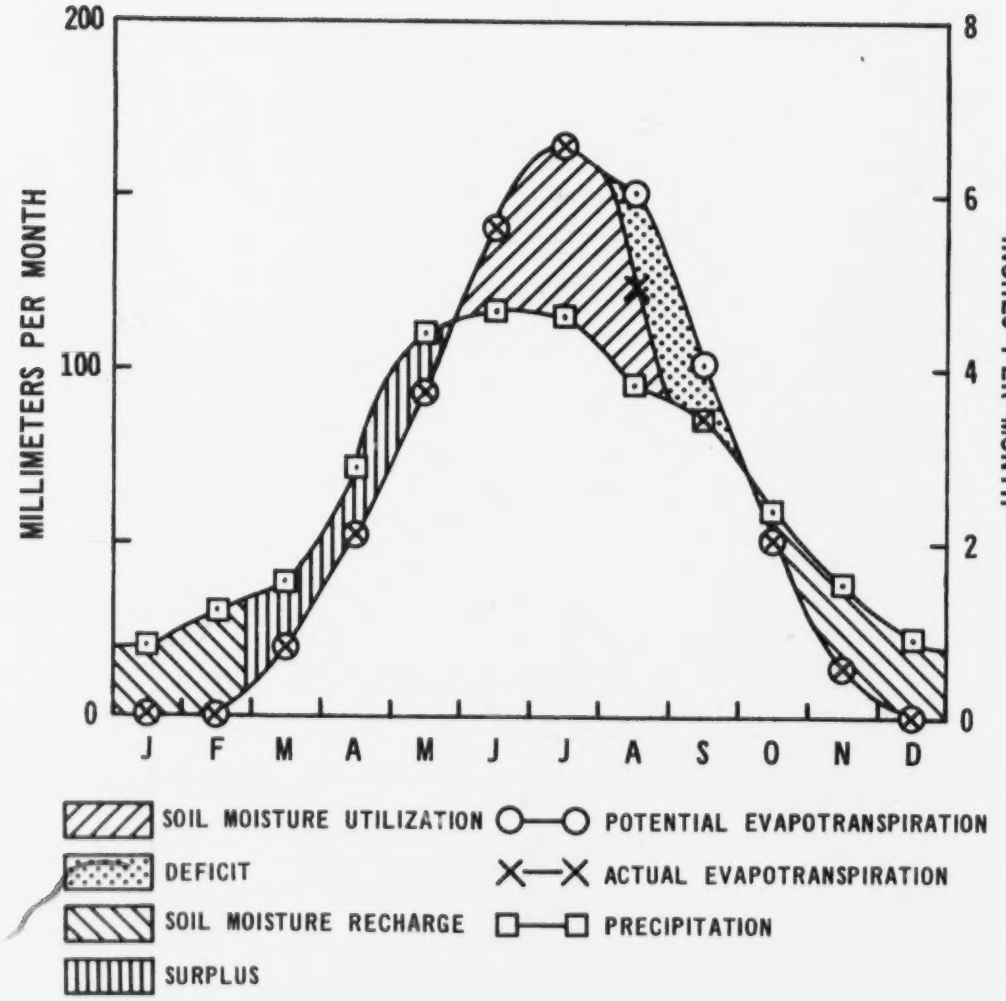


Figure 2 Average Monthly Water Budget for Manhattan, Kansas (millimeters)

evapotranspiration as it is needed to supplement the precipitation endowment during the period when PE exceeds precipitation until soil moisture is depleted. Further unsatisfied demand for moisture constitutes drought, whose magnitude is conveyed by deficit. The deficit at Manhattan of 41 mm., versus 380 mm. at Cloverdale, demonstrates the inability of precipitation at both places to keep pace with moisture demand, and the limited ability of the soil to carry forward in time a reserve of moisture to supplement precipitation.

The climate at Cloverdale generates the greater surplus, but the accordance of energy and moisture produces more evapotranspiration in Manhattan. This suggests that Cloverdale is humid for hydrologic systems, but less so for biologic systems; at Manhattan the relationship is reversed. Each place has an environment that is conducive to a high rate of functioning of some systems, and antagonistic toward others. Which of these places is the more humid?

**Why the Water Budget?**

We have argued that work in an environmental process is not done by precipitation nor by energy in the forms and quantities they are endowed upon the interface region. The purpose of a water budget is to partition precipitation into estimated capillary water flow (AE) and storage (ST) or gravity water (water surplus, S), considering the concurrently available energy. These are the quantities which are effective for environmental work; the endowments aren't. What the water budget achieves is a translation from energy (expressed as PE) and precipitation endowments into AE, ST, and S, the effective elements in environmental work.

Precipitation and temperature have been the predominant measures employed to compare to environmental work or to the distributions of products resulting from work in environment. Yet, temperature and precipitation are both ambiguous indicators of work in nearly every environment. Temperature, for example, may be correlated with increasing growth conditions, but its highest values are likely to be associated at some times with adequate moisture and at other times with inadequate moisture for environmental processes such as growth to be sustained. Accordingly, temperature in part of its range is subject to great ambiguity; and, we cannot identify the effect of the adequacy of moisture on temperature's veracity from the data of temperature alone. There is much "noise" in temperature values which can be eliminated by estimating AE, the only parameter which expresses both the effects of available energy and the availability of capillary water.

Precipitation is also an ambiguous element. The examples for Cloverdale and Manhattan in the previous section showed that precipitation's effectiveness for capillary water or gravity water depends upon the energy available for potential evapotranspiration. When precipitation amounts are less than PE during a period (when precipitation amounts are small in most climates) an increase in rainfall has a beneficial effect on growth and other processes which depend upon capillary water. Yet, in periods when precipitation exceeds PE, an increase of rainfall does not affect the already sufficient capillary moisture but it does increase the quantity of gravity water (water surplus). It is usually impossible, however, to know from precipitation data alone whether an increase in rainfall amount will affect the capillary or the gravity water, or both. It is necessary to consider the concurrent energy conditions and the antecedent effects on capillary moisture storage. That is what the water budget achieves.

The water budget examples given previously illustrate the procedure for considering simultaneously the energy and precipitation endowments and the storage effect. The period employed is intended as the representative year. Its simplicity is its merit for introducing the idea of budgeting. Its simplicity is also its limitation, so for practical applications it is advantageous to compute daily water budgets for many years of record at a place. The frequency of AE, ST, and S may then serve as a basis for comparing the frequency of measured work events such as growth, streamflow, etc.

Although the water budget long has been included in physical geography courses, it is generally presented only in the form of the representative year and it

has been an optional item for study. *The water budget procedure is not essential to a physical geography which has as its goal the explanatory description (the only kind of description?) of features of environment. In the alternative which we propose, the water budget is not a mandated objective; but, assessing the work associated with AE, ST, and S is our objective. Accordingly, the water budget is essential as a tool because it is the only available procedure for estimating these quantities from the ambiguous energy and precipitation endowments.*

**A Focus on Work at the Interface**

The definition of the physical geography we propose was given as the working of the interface environment. Eventually, when measurements of energy allocation among systems in environment are available for many situations, this objective may be attainable absolutely. Then, it will be possible to determine the efficiency of various processes to utilize energy in their work. At present, the energy measurements we desire are not available, so the efficiencies of different species of plants, different minerals, etc. to respond to a given energy availability are not known in absolute terms. Consequently, it is not possible now to calculate absolute amounts of work in systems. Yet, a potential energy availability might be computed presently from the estimated capillary water exchanges and gravity water flow at places.

The approach we urge is one of reasoning about processes in the interface from the standpoint that water must be present for energy to be effective in the work of all systems but the atmosphere. Since water occurs in two forms which are associated with very different working conditions, capillary water and gravity water may be estimated with some paradigm so that the timing during the year of these two regulators of energy's access to interface processes may be determined even though the absolute amount of work is not capable of calculation for lack of information on the efficiency of work processes. Since efficiencies of energy utilization appear to be the same within the same process, it has been possible to use the estimated amounts of capillary or surplus water as indicators of relative amounts of work in specified process from one period to another and from place to place.

Because temperature and precipitation are ambiguous endowments, though their measurements have been the customary data base for correlation with the results of work processes, much of the work of environmental sciences should be re-examined for alternative interpretations and for possible improvement in predictability of results. If some of these tasks could be brought within the physical geography course, they would provide both a practical purpose and a pedagogic situation demanding the application of the principles of reasoning upon which the course is predicated.

The kinds of concerns for a physical geography course might be considerably altered by the proposed model. If the task is continually to consider the designs by which capillary and gravity water are involved in the work of systems, there may never be an attainment of finality in our knowledge. Similarly, to consider

strategies for society's management of the operating environment may neither be completed nor stereotyped. The description of many features, or *things*, in the environment probably could not remain an objective of physical geography if argument about the working of environment that produced these features is demanded. The facts of the landscape are needed, not as objects to be memorized but as evidence for testing arguments about processes. Some ideas on the change in emphasis which would seem appropriate for an alternative view of physical geography are considered in the next section.

CHAPTER IV

# IMPLEMENTING THE CONCEPT OF THE INTERFACE WORKING ENVIRONMENT IN PHYSICAL GEOGRAPHY

If a focus on environmental work in the interface region here at the surface of the earth is taken as the core of a physical geography course, the concepts in this focus can be dealt with efficiently by examining their operation in particular systems. However, because we are interested in making an alternative physical geography course a convincing treatment of environment's functioning at the interface region—not a treatment of environment in its entirety—we shall have to forego the notion that the course is concerned with everything that environs us. Instead, those systems might be examined which lend themselves to demonstrating that environments have characteristic progressions of several kinds of work, that the work is turned on and shut off by jointly acting energy and moisture, and that the budget of energy and moisture at the interface also accounts for the work of systems in various sequences.

The systems we consider here are exemplary only; they do not necessarily define a course of study. Their purpose is to indicate that an alternative physical geography can have a distinct coherence of its parts and can address the working of environment in a way which draws on other sciences for data but not for purpose, and largely not for methodology. The systems which have been selected for consideration are the soil, biologic, hydrologic, geomorphic, and the man/environment management confrontation. In addition, we deal with the issue of new global tectonics and the difficult question of the role of the atmosphere in an alternative physical geography.

## Work in the Soil System

The notion that soils should be capable of supporting life is an agronomic bias which we need not adopt in physical geography. The wider meaning which includes soils as constructional material can be accommodated by the approach we propose. Work of a mechanical nature is performed when the soil matrix is moved or rearranged by forces of the environment. When creep, mudflow, or landslide motions occur, we see examples of work which have a pronounced seasonality or episodic character and are due to the environment's operation on the stick and slip characteristics of soil that arrest or initiate movements. Similar properties are involved when the cohesion of soil particles is affected in dam and road construction and performance or when traffic moves over soils. In all these examples the soil system is moved or rearranged mechanically by the effects of frost and/or water. Of course, frost has no effect without water, and the amount of

work, as movement, which is achieved by frost depends upon the volume of water which is frozen. This is not a question of energy conditions alone but it depends upon the budget of water in the soil sediment or rock materials which contain it. Throughout the world, mass movements in which frost is not a factor may be predominant. Here, too, gravity water holds the key to the timing of work. Could a physical geography which studies the timing of work supply expert consultants for earth construction, mass wasting, or slope failure hazard analysis in the public interest?

The chemical work of the soil is somewhat different from the ordinary test-tube variety of chemistry. Soil is so dominated by large oxygen atoms which occupy 90% of the volume of soil solids that the negative electrical properties of oxygen protrude through the solid materials and influence chemical behavior of dissolved, ionized elements. Positively charged ions (cations) are preferentially attracted and held electronically to solids, especially to the clay and clay-like materials in the soil. A compound which is ionized in the capillary water of the soil experiences a rejection of its negatively charged ions by soil solids so that these ions may pass through the soil in solution with the leaching gravity water. By contrast, its cations are attracted to storage sites on the solids and may be exchanged for other ions on the solids. Soil chemistry is complicated by this preferential storage phenomenon. Management of the soil's ionic storages is the purpose of fertilizer applications. Although the procedure for applying fertilizer is not often very precise and there are then quite nasty pollution problems, the design of fertilizer additions is an ideal which has a budget procedure as its basis that can be manipulated by students. It is a problem involving concepts similar to chemical weathering and leaching of soils.

Work done in environment by weathering processes occurs predominantly in soil. It depends ultimately upon the endowed driving forces of energy and material inputs; however, utilization of energy in decomposition schemes not only is dependent upon how much the environment receives but is governed by numerous extenuating circumstances such as rock composition, organisms, etc. The problem for a model of weathering is to represent the effectively available forcing function as well as how much of it becomes "connected" into a weathering situation. For a simple chemical weathering model, the essential assumptions become: 1) the reaction products for an amount of material undergoing weathering are directly proportional to the amount of available energy while capillary water is present; and 2) the various materials undergoing weathering and the extenuating factors comprise a suite of discretely different "efficiencies" or coefficients.

For a majority of chemical reactions, the governing energy may be indicated conveniently by AE; whenever coldness or dryness cause AE to be small there is little weathering; when AE is large, weathering is auspicious.

The "efficiency" or coefficient term of the simple model of weathering may (or may not) include a host of related effects in addition to differences in reactivity of mineral type such as amounts and kinds of organisms, the ionic content of precipitation and pH of the soil solution, the surface area of reacting materials, and possibly many other factors. It should be noted, however, that all these conditions

operate not as forcing functions but as regulators of the efficiency of the main forcing conditions. The effects of main contrasts in vegetation, pH, ionic content, etc., also may themselves be largely subsumed in the energy and moisture surrogates or indices that characterize a place.[9]

One means by which organisms affect the efficiency of weathering in the soil is through the decay of organic debris. Organic matter that decomposes at the surface yields organic acids to infiltrating moisture and thereby makes solutions more potent as solvents and chemical reactants. Furthermore, the decay of organic debris is largely accomplished by a host of micro-organisms which not only break down the organic material but make their own energy and material demands on the soil. Though the evidence is far from conclusive, these chemical and physical demands of plants and other organisms may be the most important factors in bringing about transformations of soil materials. If this be the case, then the energy and moisture endowments which drive the biologic system also may dominate the efficiency factors of the soil weathering system.

Surplus is the driving force for leaching, so leaching occurs only when surplus is being generated. If we assume that the efficiency of a unit volume of surplus is constant through time (a first approximation only, since the acidity of water may change with temperature), then the timing of leaching occurs proportionately to the timing of surplus. Figure 3 was developed under this assumption. It shows the surplus for Cloverdale (606 mm.) and Manhattan (58 mm.), as computed with a water budget. The striking aspects of the implied leaching at these places are the similarity in seasonality—both places experience leaching during the winter and early spring—but there is a great variation in the quantity of water available to transport soluble material through and from the soil. Cloverdale experiences a longer season of leaching, and more intense activity than does Manhattan. This is in contrast to the availability of energy when capillary moisture is present. Relatively, Manhattan has more power to weather minerals, as Figure 4 shows, but less power to leach than does Cloverdale.

The actual rates of leaching as with all processes powered by environmental energy and moisture, is a function of both the magnitude of input and the efficiency of response to the input by the system. Only if the substrate at Cloverdale and Manhattan were the same would one expect the same efficiency of weathering and leaching. If the relative efficiency of different soils and rock strata are qualitatively known, certain groupings might be made in order to draw more specific conclusions about weathering of the substrates at Cloverdale and Manhattan and would have to be addressed in order to deal with absolute rates of weathering. Furthermore, it would be hazardous to conclude from these efforts to model leaching and weathering about the relative work accomplishment in each system, since the efficiencies between systems could vary more than they do from place to place for a given system. A general model of weathering is sorely needed. It would have application in estimating the residence times of pesticides and radio

[9] Weinert, H. H., "Climatic Factors Affecting the Weathering of Igneous Rocks," *Agricultural Meteorology*, Vol. 1, (1965), pp. 27–42.

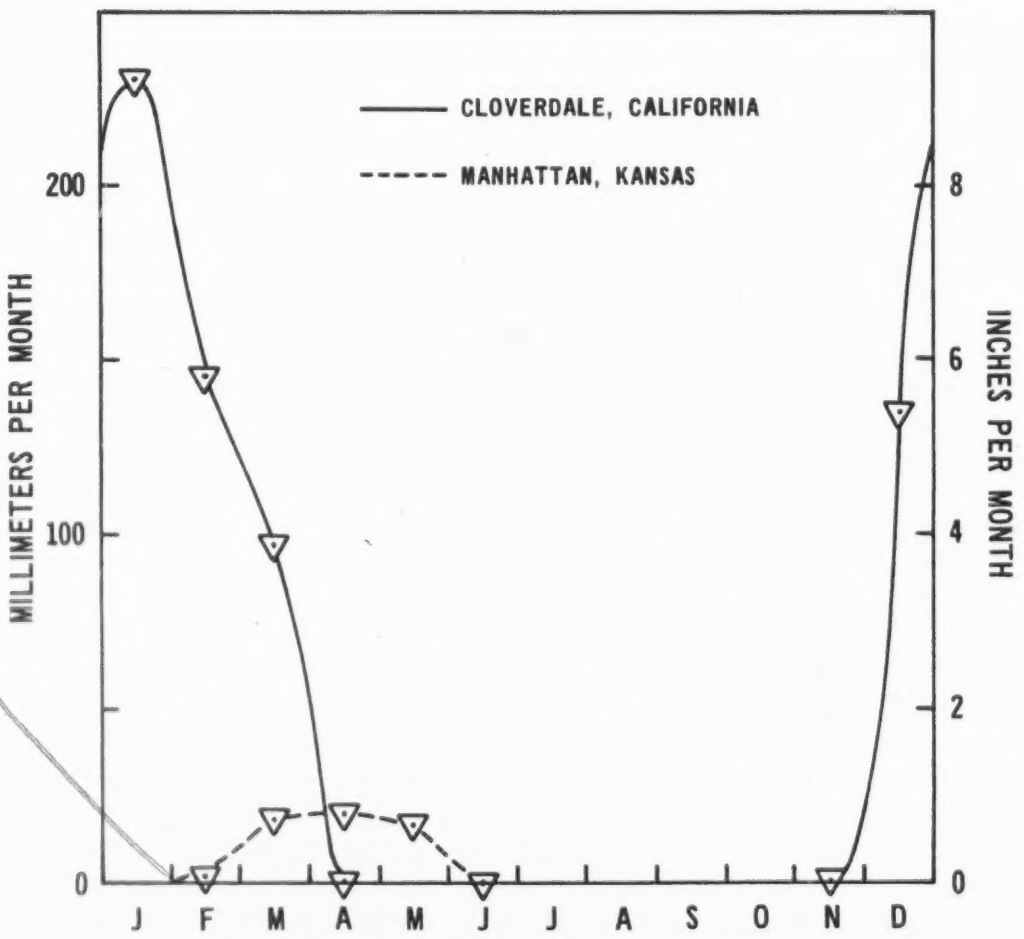


Figure 3 Seasonality of Leaching in the Soils System Expressed by Water Surplus at Cloverdale and Manhattan

nuclides in soils and it could direct our management of nutrient cycling whether from waste metals, mine spoils, landfill, or prodigal irrigation. If we really understood weathering and leaching, we might make so bold as to "grow" the soils we shall need in the future and in the places where they will be most needed.

In well-drained soils, the production of ions, their storage, and removal tend to have regional patterns like vegetation or climate. The humus accumulation of soils, their pH, the depth of horizons, and clay content may also be crudely regionalized. Such tendencies toward regular distributions strongly suggest that the work of the soil has a gross pattern which is due to energy and moisture endowments, yet the critical features which are pertinent to local management often are more dependent upon texture and slope which do not exhibit the same broad regional tendencies as the environmental endowments. There are then two scales of questions concerning the chemical work of soils which geographers might consider. On the one hand, are the perplexing, general, regional tendencies with little practical application. On the other hand, there are local distinctions such as texture which differentiate

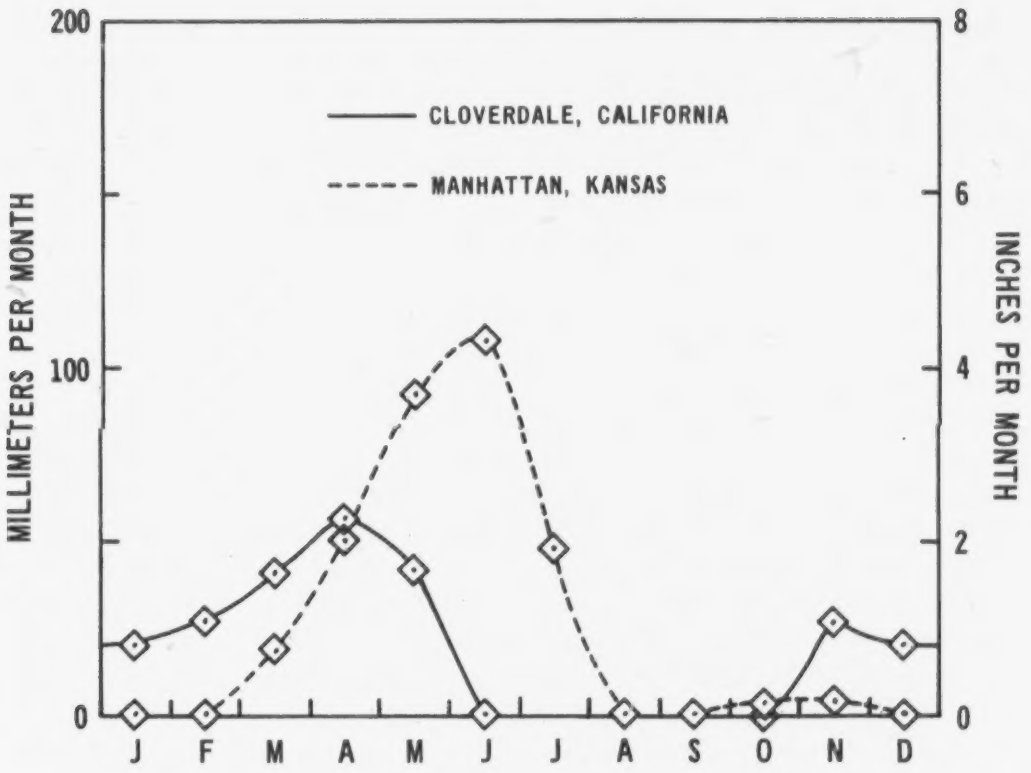


Figure 4 Seasonality of Weathering in the Soils System at Cloverdale and Manhattan

operational problems and result in greatly different work experiences with adjacent soils. Both, obviously, must be elucidated by the effectiveness of AE, ST, and S regimes.

The importance of biologic activity to the soils system has been alluded to, but its modeling deferred until the discussion on biologic systems. We now turn to these systems to explore them in their own right, and to complete the discussion of soils systems.

**Work in the Biologic System**

Organisms and ecosystems have developed the capacity to capitalize upon the basic regularity in their environment and to buffer its perturbations for the sake of their survival. They have an inherited strategy through which the influxes of energy and moisture are brought to bear on processes prescribed by the plant. It is the organism that is organized to allocate the energy and materials from the environment to be engaged in growth and other organism processes. On the other hand, the inputs from the environment are fundamental in forcing functions to make the biosphere work. It would be inert, inorganic matter if an external source of energy and moisture were not provided for a time.

The operations of ecosystems and organisms are timed as though thoughtful observations and decisions of a "brain" were at work—even in lowly plants; also,

the cells and tissues in an acre of organisms behave like a mighty factory for they must process prodigious volumes of materials. The brawn of an acre of an ecosystem is demonstrated by its ability to extract requirements from more than 20,000 tons of air per year[10] and 2,000 tons of water. Both the brain-like activity and the brawny growth of plants are regulated by the energy and moisture conditions which operate the water budget.

The seeming intelligence of a plant is concerned with recognizing environmental signals and regulating the sequence and timing of the plant's operations. Specifications of how a plant will operate are part of its inherited chemistry, but the energy and material with which it actually works are supplied by the environment in the water budget and its associated light energy. The design of plant operations apparently is contained in every cell; this inherited chemistry produces tiny amounts of additional, special chemicals for detecting environmental signals. Two such signals, the duration of daylight and darkness, are measured chemically in the signal detecting mechanisms of plants and their relative effects are used as a biologic clock to prevent plant operations until the ratio of darkness to light is as required. Some biologic operations can be timed to the day by this device. Many other "decisions" apparently are timed by the completion of recent accomplishments of plants. This kind of timing seems to be tied to energy or moisture flows rather than to light conditions. Part of the plant, acting like a "brain," "knows" how to recognize environmental signals so it doesn't commit the plant to operations until the plant's plan is met. The sequence of projects, such as leafing, fruiting, etc., is "known" infallibly and controlled through some communication scheme of the plant chemistry. The latter requires extremely small amounts of specialized chemicals as messengers. Environment paces the plant through its effects on delicate chemical relations.

The brawn of plants is supplied by environment but it is directed by the "brains" to constructional or destructional activities. Primary productivity is derived from photosynthesis which converts physical energy of the environment into chemical energy in compounds. Since storage of energy in photosynthate is not great compared to plant needs, construction projects by the plant are largely keyed, or timed, to concurrently available energy and moisture for the photosynthesis process. Antithetically, plants consume more than half what their photosynthesis produces. This "destructional" activity is also regulated by the environmental energy and moisture. The resulting growth, or net productivity in vascular plants, determined as photosynthesis minus respiration, is considered by ecologists to be proportional to evapotranspiration. Thus, the timing of accomplishment and the amounts produced as "growth" or biomass accumulation might be directly identifiable from the energy or water budget. Modeling growth by the energy budget approach is quite involved, and it requires a water deficit to translate

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[10] Norman, A. G., "The Uniqueness of Plants," *American Scientist*, Vol. 50, No. 3 (September, 1962), pp. 436–449.

potential growth into actual yields.[11] With the exception of wet, hot regions, rates of energy expenditure for evapotranspiration and growth fluctuate considerably from any consecutive period to another. The idea of a budget inherently expresses varying rates of progress of plant development, and different amounts of mass accumulation in nearly every time unit.

A budgeting framework provides surrogates of both the pacing and the powering for the biosphere. Thornthwaite's scheduling of crops for a frozen food processing corporation demonstrated that the pace of maturation of crops bears a consistent relation to the rate of accumulation of units of potential evapotranspiration.[12] The accumulation of biomass has been shown to be a function of cumulative actual evapotranspiration for irrigated and unirrigated crops in California,[13] and for natural vegetation over a wide range of climates.[14] Sequences of dormancy and growth of natural vegetation in a variety of climates bear a consistent relation to the regime of actual evapotranspiration.[15] The distribution of major plant communities is bounded by orderly values of AE, PE, and water deficit.[16] An understanding of the performance of domestic and natural vegetations lends added reasonableness to human activity. The regime of agricultural activity coincides with the regimen of energy and moisture circulation at the interface, as Curry has illustrated, again with the aid of the water budget.[17] These examples of water budget applications illustrate two principles of productivity: 1) the pacing *development* of plants from one recognizable state to another does not occur in a constant time interval from year to year; rather its fundamental constant is the accumulation of a specified energy (PE); and 2) the *mass accumulation* by plants is proportional to their transpiration (AE). If this year's water budget is characterized by a warm spring, the accumulation of the energy required to pass from emergence to fruiting, etc., is the same as ever, but it takes fewer days in warm weather to achieve it. Furthermore, should this summer be usual in all respects except that it is quite dry, the yield of crops should be expected to be reduced, in proportion to the reduction of AE. These ideas about productivity are somewhat more useful than

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[11] Albrecht, James C., *A Climatic Model of Agricultural Productivity in the Missouri River Basin;* unpublished doctoral dissertation, Southern Illinois University, 1971.

[12] Thornthwaite, C. W. and J. R. Mather, "Climate in Relation to Crops," Recent Studies in Bioclimatology, *Meteorological Monographs,* Vol. 2, (1954), pp. 1–10.

[13] Arkley, R. J. and R. Ulrich, "The Use of Calculated Actual and Potential Evapotranspiration for Estimating Potential Plant Growth," *Hilgardia,* Vol. 32, (1962), pp. 443–468.

[14] Rosenzweig, M. L., "Net Primary Productivity of Terrestrial Communities: Prediction from Climatic Data," *The American Naturalist,* Vol. 102, (1968), pp. 67–74.

[15] Major, Jack, "A Climatic Index of Vascular Plant Activity," *Ecology,* Vol. 44, (1963), pp. 485–498.

[16] Mather, John R. and Gary A. Yoshioka, "The Role of Climate in the Distribution of Vegetation," *Publications in Climatology,* Vol. 19, No. 4, (1966), pp. 372–384.

[17] Curry, Leslie, "Climate and Economic Life: A New Approach with Examples from the United States," *Geographical Review,* Vol. 42, No. 3, (1952), pp. 367–383.

alternatives such as rainfall correlations against yield or the claim that it requires a certain number of days to mature a crop in a particular climatic zone.

Nearly all relationships within an organism are dependent upon productivity considerations. Productivity also is the basis for succession, competition and cooperation among organisms for the number and variety of indigenous species at a place, for the functioning of ecosystems and for our sustained management of the biosphere. Decay is another extremely important feature of ecosystem and organism functioning to which our interest should apply. All residual production by organisms, even the food chain which feeds us, eventually is contributed to the decomposer food chain. Here, energy, moisture, and nutrients are freed from matter. However, the rates of work by decomposer organisms are directly dependent upon the amount of energy available while capillary water is available. Decomposition varies as AE varies.[18] It is greater when energy increases, provided water is concurrently available in capillary films.

Like productivity, decomposition is a place attribute and it varies with the weather, according to energy while water is available. Environments, then, are capable of processing various amounts of waste in a period of time. The wisdom of concentrating waste in environments which are frozen or those which are dry needs scrutiny. One needs to consider AE when judging the efficacy of shipping San Francisco's discarded artifacts to an arid preservation in Nevada, or the wisdom of separating liquid waste from solids in Phoenix, Salt Lake, or Las Vegas middens. In such problems, the environmental power may be the critical factor in decisions on waste disposal.

Actual evapotranspiration is a water budget operator which is surprisingly facile in expressing the work accomplishment in terrestrial biologic systems. It has a quantitative relation to both crop and forest productivity, and to the work of decomposition. In fact, the use of AE to model biologic activity provides the most explicit statement of the work accomplishment of environment that we have discovered.

The regime of activity in biologic systems is shown for Cloverdale and Manhattan in Figure 5. The biologic system has considerably greater input of useful energy at Manhattan than at Cloverdale, especially during the period of high PE shown in Figures 1 and 2. While the potential productivity as estimated from PE alone is comparable at both sites, the strikingly different moisture regimes foster contrasting biologic activity. The implications for agricultural land use at these places is apparent. Cloverdale must accommodate two periods of reduced production while the productive season at Manhattan is suited to a fixing of many more calories per year. Irrigation could improve productivity at either place but it would be more dramatically effective per unit of water added at Manhattan.

The pacing of the decomposer food chain is indicated in Figure 5. Decomposition and growth are concurrent in time as well as in space in natural ecosystems.

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[18] Meentemeyer, Vernon, *A Climatic Approach to the Prediction of Regional Differences in Decomposition Rate of Organic Debris in Forests,* unpublished doctoral dissertation, Southern Illinois University, (1971).

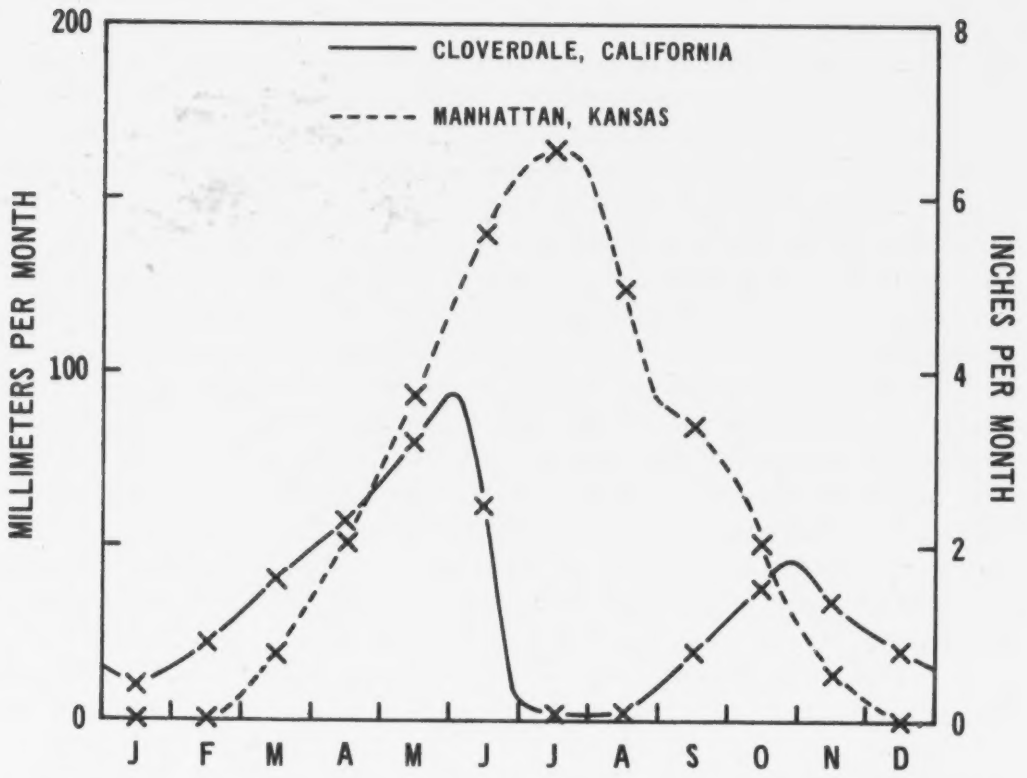


Figure 5 Coincident Seasonality of Growth and Decay in the Biologic System at Cloverdale and Manhattan as Indicated by the Regime of Actual Evapotranspiration (millimeters)

Growth currently draws upon the nutrient resources which were involved in preceding growth but now are being released by decay. The implications of this timing of concurrent growth and decay rather than a sequential pattern of growth-decay-growth in successive seasons for biologic and soils systems will be discussed below after we deal with the hydrologic and geomorphic systems.

**Work in the Hydrologic System**

Water gets into and out of every system operating at the interface. It is involved in the operations of those systems often as a main forcing function. In all the systems of environment, even in the rock cycle, water is involved as a driving force, or as a modifier of nearly every process. Water also is involved in a system of its own—the hydrologic cycle. Now, we shall look at the regional conditions of rivers and water bodies to which the local water budget is a supplier of water surplus on occasion.

Water bodies have a water budget of income and outgo which could be considered to have practically no storage restrictions. Thus, their budgets differ from the water budget for land areas markedly with respect to capillary storage and water deficit, although potential moisture loss also may be modified somewhat over water. The budget of water gains and losses affects some important physical and

chemical conditions of water bodies. For example, the oxygen content of deep waters in partially enclosed seas is governed by the evaporation loss in comparison to fresh water gains. Some seas such as the Black and the Baltic are poorly supplied with oxygen, while others such as the Mediterranean are ventilated and rich in oxygen to great depths. The Mediterranean loses more by evaporation than it gains from the combined rainfall onto it plus streamflow. Its surface salinity and density are thereby increased, so the surface waters sink, carrying their dissolved oxygen to great depths and ventilating the basin. By contrast, an unventilated basin receives more fresh water volume than its evaporation loss so that the fresh water tends to remain afloat and to move over the surface horizontally to the connecting ocean or other receptacle. Waves mix the fresh water only to shallow depth, and there is no vehicle to carry oxygen deeply in an unventilated basin. These contrasted oxygen distributions are paralleled by drastically different ecologies in water bodies. Where irrigation development and reservoir construction augment evaporation and so diminish streamflow to certain water bodies, these upstream events may greatly alter the hydrologic balance, thus the chemical and ecologic character of lakes or seas, with enormously important consequences for activities which are predicated on a maintenance of the existing conditions.

Terminal lakes in dry regions are excellent examples of feed-back in systems. As the chemical load of the terminal lake increases, its evaporation rate declines. Precipitation onto a lake in dry regions is inadequate, by definition, to match the potential evaporation loss, but a terminal lake receives streamflow from a drainage basin. The depth of surplus on the drainage basin multiplied by its area is the volume of streamflow to the lake. That quantity, in the long run, must match the net loss of evaporation minus precipitation for the lake area. Thus, the size of the lake must adjust so that its area times its interface water budget deficit (or depth) matches the volume of inflow. Where the beach of a terminal lake is important for recreation, some ordering of water use on its watershed may be feasible to manipulate the size of the lake.

Swamps, marshes, and phreatophytic vegetation along streams may also have water budgets in which water deficit does not occur because water is available at the surface or to shallow roots in unlimited supply. Eradicating phreatophytes and draining these areas usually decreases actual evapotranspiration in the hot season. There is then a resultant gain in water resource which can be detected in the streamflow record over time (its hydrograph).

The stream hydrograph is comprised of water transmitted rapidly to the channel plus water delayed enroute by more difficult transmission routes. The tradition is to divide these into two parts: the surface water flow and the base flow components of the discharge. This is probably a great oversimplification of a variety of pathways taken by water surplus to the stream channel. If water surplus of a period is computed for the watershed, and if it is quantitatively equivalent to the measured discharge, there is a good problem here for a physical geography class to ascertain the "decision" rules for water using various pathways to produce the observed hydrograph.

Hydrographs show channel discharge against time. The hydrograph of humid basins in the mid- and high-latitudes have maximum flows in the period generally from February to June. The effect of snow melt and "glacier fed" streams is often suspected of responsibility here. But a February or March maximum flow for basins in Alabama, Georgia, and Mississippi isn't due to snow melt. The water surplus is maximum in the cold season in mid- and high-latitudes because evapotranspiration is restricted then. Precipitation in autumn or early winter may occupy the capillary storage of soils without significant depletion between storms. Finally, capacity is reached and any ordinary storm almost entirely runs off because there is no available capillary storage. Thus, coolness makes rivers run heavily in humid areas. Many of the humid parts of the United States have maximum precipitation in summer but the maximum streamflow comes in spring or late winter, as it does at Manhattan, Kansas. Summer precipitation usually is accommodated by intense evapotranspiration and a considerably dried out soil storage space. Thus, the rivers run full just *before* the maximum rain season. It appears they run in *anticipation* of the heavy rains.

Streamflow is a residual; it is moisture that could not be stored in capillary pore spaces in soil. Whether there is now room to store rains as capillary water, thus preventing streamflow, is mainly a matter of conditions of evapotranspiration since the previously infiltrating rainfall. The soil's capillary water pore spaces are vacated primarily through the efforts of transpiring plants. Plants remove moisture from their entire rooting depth, which usually extends a couple of meters into the soil. Changes from deep-rooted to shallow-rooted vegetation may have a substantial effect on the volume of capillary water storage and thence on streamflow.[19] Much hydrologic research in the twentieth century has dealt with the ways in which streamflow can be altered through manipulation of vegetation and the root zone capillary water storage. More recently, attention has been given to the inadvertent increase in streamflow that results from urbanization. Substitution of lawns for deeper rooted natural vegetation decreases evapotranspiration by limiting the available soil moisture during the summer, and thereby increases the portion of precipitation allocated to surplus. Paving, roofing, and trampling of soil surfaces decrease the soil infiltration capacity, and shift the allocation of precipitation primarily to surface runoff and away from the storage, evapotranspiration, and more leisurely ground water runoff of unmodified areas.[20,21] As a consequence, base flow is greatly diminished, and the urbanized stream becomes more "flashy"—base flow may be replaced by the regime of effluent flows from the local sewage treatment plant.

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[19] Muller, Robert A., "The Effects of Reforestation on Water Yield," *Publications in Climatology*, Vol. 19, No. 3, (1966).

[20] Muller, Robert A., "Water Balance Evaluation of Effects of Subdivisions on Water Yield in Middlesex County, New Jersey," *Proceedings*, AAG, Vol. 1, (1969), pp. 121–26.

[21] Bohnert, John, *The Effect of Urban Land Use on Total Runoff: A Case Study for Salt Creek Basin, Cook and DuPage Counties, Illinois*, unpublished doctoral dissertation, Southern Illinois University, (1971).

Streamflow is generated by surplus, the same quantity that is involved in leaching or surface erosion. Figures 1 and 2 show that surplus is generated for only four months of the year at Cloverdale and Manhattan. Surplus is not generated for fully six months of each year at most places in the mid-latitudes, yet the rivers continue to flow. Streamflow lags behind surplus to the extent that it is base flow, the delayed outpouring of aquifers which temporarily store the water, and permit it to flow to the channel over a period of weeks or months. The extent of the lag depends upon the quantity of water involved, the nature of the substrate, and the size of drainage basin. A convenient expression of this lag is the half-life of the ground water, the time it takes one-half the water surplus of a period to appear in the stream channel. For a month's water surplus, this has been calculated as several years for large river systems underlain by aquifers having large storage capacity, to a few days for the aquifer feeding on an ephemeral stream near a ridgetop. For river basins of moderate size, a half-life of one month has been found to be a reasonable approximation of reality. This rule-of-thumb permits us to transform surplus derived from a water budget into streamflow shown in Figure 6. Comparison with Figure 3, which shows the surplus as it is generated, illustrates to what extent the ground water zone causes streamflow to lag behind surplus. While the flow of streams may extend throughout the period when no surplus develops, most of the surplus has been converted to runoff within a month or two after the end of the season of surplus. After that, streams and rivers become progressively more sluggish.

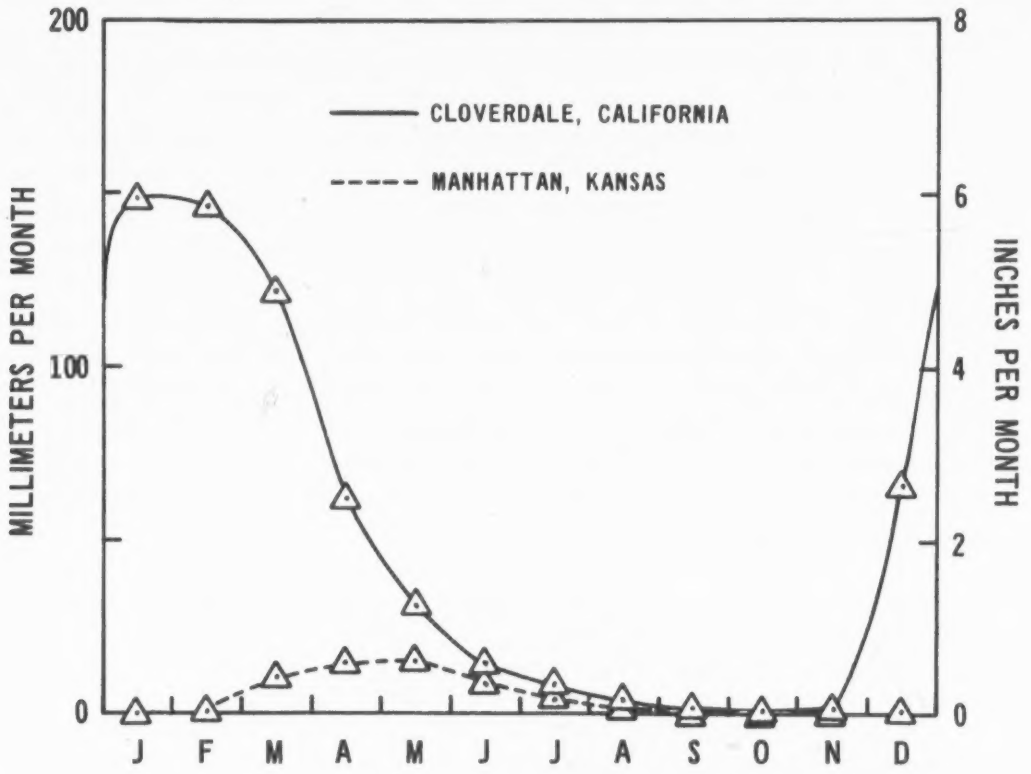


Figure 6 Seasonality of Streamflow at Cloverdale and Manhattan

The effects of urbanization on streamflow can be simulated by students who understand that statements about allocation of precipitation to surface runoff, soil moisture, and ground water at the interface can be incorporated into a water budget designed to imitate local realities. But hydrologic operations are not merely a classroom puzzle. Hydrology affects very directly all the systems in nature, so it behooves us to attain some sophistication about the timing of work it induces in environment. Hydrology may be the *sine qua non* of physical geography. Hydrologic relations are critical to model building for environmental systems and thus to solutions of problems which benefit from analysis by a synthetic hydrology which projects conceptually the results of a changed hydrologic system with specified conditions for input, storage, and output of water.

**Work in the Geomorphic System**

The geomorphic system is concerned with landforms and therefore deals with a number of processes which were encountered partially in previous topics such as weathering and mass wasting of soil, or the flow of streams and ground water. Landforms are monuments to the work of all these processes and of the work of tectonic movements. Also important are many factors which affect the work of denudational processes such as erodibility of materials and degree of slope. Such features modify the efficiency of the forcing functions but are not themselves generators of action in the system. The forcing functions are the energy associated with the flow of water surplus as well as capillary water storage and flows.

Although it is quite obvious from consideration of the water budget that there is a seasonality in the operation of the geomorphic forcing functions which are supplied from above the interface, it is customary to neglect seasonal contrasts in the operations of the geomorphic system for the most elementary models of the geomorphic system, such as those established by Davis. Not only the seasonal contrasts are neglected in these models but also the episodic events which represent the disproportionately effective seasonal geomorphic work events in a long period. Traditional models have suggested correctly that denudation of land is due to weathering, mass wasting, and transport but the impression that these processes are continuous, steady, and not catastrophic has been fostered or permitted to prevail in accounts of the geomorphic system such as Davis proposed. Consequently, the performance of denudation has tended to be looked upon as an equilibrium condition of one complex operation. The work and the timing of component processes have not been sufficiently investigated to provide an alternative to the traditional, inductive models.

The growth of morphometry, especially in the United States, and of climatic geomorphology, especially in Europe, are the two major developments in geomorphic philosophy since the days of Davis. Although they have precious little in common, both developments contend that they differ significantly with Davisian philosophy. Morphometry adherents have shown that a great many regularities exist in such diverse matters as: the geometry of basin characteristics and stream elements; interdependence in measures of channel flow characteristics; and indices

of areal denudation. Although morphometry has dealt with streamflow as virtually the only forcing function, its impact is powerful but piecemeal. It has provided the most violent shaking of the Davisian models, yet there is no comprehensive theory of morphometry which would permit one to predict or even to generalize how weathering, mass wasting, and stream transport processes work together in the denudation of areas.

Climatic geomorphology has been devoted mainly to demonstrating that regional distinctions in landform characteristics match the extent of present climatic types and to showing that the nature of past climates can be identified by products presently produced under the influence of some existing climatic type. Climate is thus treated on the broadest scale and largely as an areal type rather than as process.

One may be persuaded to agree with Stoddart[22] that climatic geomorphology is entrapped in its own historical and regional preoccupation and is not yet significantly different from Davisian or classical geomorphology. Yet, climatic geomorphology contains an implied challenge were one to attribute geomorphic change in landforms primarily to climate as process: i.e., as the power of environment at work in weathering, mass wasting, entrainment, and erosional transport or deposition. Although climatic geomorphology doesn't seem to have conceived of climate explicity in a work context, this notion may be intended by some workers and certainly should be valuable for climatic geomorphology. If it adopted the concept of climate as achieving work instead of climate as region, climatic geomorphology might contrast strongly with the Davisian ideas. Instead of the Davisian tenet that slope is the main indicator of the intensity of denudational work, climatic geomorphology could claim that denudational work is a variable, dependent primarily on the working climate at the interface–the power of environment in weathering, mass wasting, and primarily fluvial transport systems. By careful selection of examples to minimize effects that could be due to material, slope, and extremes of vegetation cover, an approximation of the mixes of weathering, mass wasting, and transport might be gotten from the timing of the indicators of work in the system, AE, ST, S, and Runoff.

The picture of denudation which would be quite useful for physical geography is a general scheme of how the system works which is also representative of local events. For example, the amount of material borne to the oceans and seas needs to be attributed to places from which it arose; if the seasonal work of weathering, mass wasting, scour, and local deposition, which is involved in this denudation were stated in terms of a budgetary framework, perhaps as Ahnert has suggested,[23] the

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[22] Stoddart, D. R., "Climatic Geomorphology: Review and Re-assessment," in *Progress in Geography:* (International Reviews of Current Research), Vol. 1, eds. Christopher Board, Richard J. Chorley, Peter Haggett, and David R. Stoddart, Edward Arnold, Ltd., London: (1969), pp. 159–222.

[23] Ahnert, Frank, "The Role of the Equilibrium Concept in the Interpretation of Landforms of Fluvial Erosion and Deposition," *L'Évolution des Versants,* (LES CONGRES ET COLLOQUES DE L'UNIVERSITÉ DE LIEGE), Vol. 40, Liege: (1967), pp. 23–41.

explanation might serve geomorphology well, but significantly it would advance the notions suggested here for a coherent physical geography whose work is driven by events in the interface region.

A view of the geomorphic system which is oriented to work events could offer a better opportunity to assess the mixes of weathering, mass wasting, and transport which characterize places and probably make for characteristic landscapes. If the denudation of land were understood in terms of the frequency of work events in each of the component processes of denudation, it might be possible to prescribe policies for land use which would result in denudation at rates compatible with costs and benefits of erosion suppression.

**Interactions Among Environmental Systems**

We have discussed the operation of soils, biologic, hydrologic, and geomorphic systems somewhat in isolation, although we know that complex interactions occur among them. The efficacy of the concept of environmental work and of budgeting procedures as its means of investigation, is largely that it provides for integration among the environmental systems. Several points will demonstrate this.

A major point made thus far is that the environmental resources of energy and moisture are allocated among systems in seasonally changing quantities and proportions. The timing of water surplus as a residual of water not processed in biologic activity but left for leaching and streamflow is a good example. Reference to Figures 3, 5, and 6 shows clearly that low-priority leaching is curtailed and streamflow declines rapidly, as plant communities increase their use of soil moisture. Vegetative needs for soil moisture take precedence in the allocation of precipitation to surplus for leaching and streamflow. In addition, weathering, mass wasting, and other work accompany each of the allocations to storage and flows in environment.

The tendency for biologic activity, expressed most noticeably as plant growth, to be the instrument for the decline in surplus leads to another fundamental interaction among systems. Recent studies of nutrient cycling in forests have demonstrated that natural ecosystems are conservative of their mineral resources.[24] The quantity of nutrients input to the ecosystem by fallout or soil weathering, and output by leaching is negligible compared to the closed cycling of nutrients between organisms and soil, in spite of the possibility of large quantities of surplus to leach nutrients from the soil. How is this accomplished, and can the models of environmental work elucidate the processes at work?

The nutrients most accessible to surplus are probably those being released by decomposition of organic matter and introduced to the soil solution. The concurrent presence of these by-products of decomposition and large quantities of surplus would probably result in significant loss of nutrients from the soil. In mid-latitude ecosystems, organic matter becomes available for decomposition

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[24] Bormann, F. H. and G. E. Likens, "Nutrient Cycling," *Science*, Vol. 155, (1967), pp. 424–429.

primarily during late summer and autumn. However, this coincides with a period of reduction in all biologic activity, including decomposition, so the organic matter remains at the soil surface in its organic state. The period of leaching which follows the shedding of leaves in the mid-latitudes cannot be especially efficient because the bulk of the nutrients are still locked up in the organic matter. At the time the pace of decomposition picks up in the following spring, the plant community effectively blocks the escape of newly released nutrients by appropriating them with most or all of the available moisture for evapotranspiration. This overview of the interaction between the soils and biologic systems suggests the possibility of discovering many subtle relations that constitute the fine tuning of these systems. One further example is the biologic activity during warm spells during winter when moisture uptake by plants and the growth of herbs may assist in the conservation of nutrients which might otherwise be borne away by surplus.

The biologic system effectively limits efficiency in the soils system; in this case, the process of leaching is regulated. On the other hand, where surplus is generated during periods of intense biologic activity, it is possible that the loss of nutrients would impoverish the soil. It may be the biologic system which most establishes the efficiency of weathering in the soils system through selective uptake of minerals and their early closed cycling in the nutrient pool of the ecosystem. Ecosystems are devastated by fires and other natural catastrophes, followed by succession toward a more stable system. What is the effect of plant succession on rates of weathering and leaching activity? How does the pioneer vegetation establish a new nutrient pool for the ecosystem after the former nutrient pool has been borne away by wind and water after disturbance? And how does man's agricultural and other resource management relate to these processes?

Thus far we have concentrated on the interface and its environmental systems without reference to the larger scale atmospheric and geologic processes that have also been a part of the physical geography course. The implication of this stress has been the paramount importance of the interface for physical geography. Yet, the atmosphere and lithosphere also share the interface, though their bulk does not lie in the interface region. The scope and nature of attention given to these extra-interface systems must be decided upon the basis of their relevance to the work of the interface region. We will deal with the atmosphere first, then with the issue of global tectonics as subject matter for a physical geography course.

### The Atmosphere in the Work of the Interface

Whether the atmosphere's qualities would be included as objects of study in the physical geography we propose depends upon their directness as factors at the interface and whether they can be characterized as part of a work enterprise at the interface. Obviously, a great deal of the traditional description in a beginning course of physical geography could not be embraced under these restraints. The proposed approach is rather a contrast to the traditional, phenomenologic inventory of weather elements, air masses, lapse rates, and classification of storms. The intent of these topics is to deal with the atmosphere in its conservative region, away from the

interface, and usually with a view to observing and representing the weather on maps for empirical forecasting. Since physical geography concerns the environment where man experiences the work of many systems, it is evident that a descriptive meteorology specifically designed to minimize or eliminate consideration of the effects of other systems must represent a contradiction of purpose. We conclude that descriptive meteorology is a completely borrowed topic which should be moved out of a beginning physical geography course devoted to the environment of man.

It is not our intent, however, that the atmosphere be forgotten in physical geography. There are many features of the atmosphere which have been treated as quantitative budgets in the literature of meteorology and climatology, though few of them appear in physical geography courses, it seems. Any conservative property for a defined period and area might be budgeted. Of course, the majority of features about the atmosphere concern the moving, developing items of that system but they truly have very indirect relations to the work of the interface systems. If we invoke the criterion that interface work must be directly involved in topics of the introductory physical geography course, there are four budgetary exchanges in which the atmosphere participates that we suggest are germane, even critical to understanding other systems in our environment. These are: 1) the energy budget; 2) the hydrologic cycle; 3) cycles of atmospheric impurities; and 4) the evolving composition of the atmosphere.

*The energy budget* deserves to be placed early in the introductory course of physical geography because energy is the essence of the concept of work in an environment of systems. Placed early, it can serve to demonstrate the general qualities of budgets, or continuities of conservative properties. Basic principles of the probably unfamiliar behavior of energy flow, work, and power can be clarified also.

Sharing of energy by systems at the interface is implicit in the work concept. However, nearly all systems are rather ineffective for incorporating the available energy into their functioning. A very large share of the energy streaming to the interface from and through the atmosphere is returned to or through the atmosphere without accomplishing any change in other systems at the interface. The considerable share of energy which is devoted to evapotranspiration demonstrates the centrality of this factor in both the energy budget and the moisture budget. The energy budget helps to demonstrate the roles played by the atmosphere and the systems at the interface in the cycling of energy and the work accomplishment through energy.

*The hydrologic cycle* demonstrates the ways in which the atmosphere interacts with the interface in terms of moisture. We have indicated that the work accomplishment at the interface by moisture delivered by the hydrologic cycle can be elucidated by the water budgeting procedure that contrasts the moisture endowments as precipitation and that portion of the energy endowment that is available for evapotranspiration or potential evapotranspiration. We feel that an understanding of the role of the atmosphere in the hydrologic cycle has a critical

importance with respect to several questions about the operation of the interface.

The scale of operation of the hydrologic cycle relates to such questions as whether a forest creates its own precipitation through a high rate of evapotranspiration, or whether droughts are self-perpetuating. It becomes of critical importance when considering the ways in which manipulation of the hydrologic cycle at the interface at one place, as by alteration of AE by substitution of one vegetation's root zone for another, can affect the hydrologic cycle of another region.

The operation of the hydrologic cycle in interaction with the interface water budget on a continental scale boldly conveys the "systemness" of the atmosphere and earth's surface. For example, although much of the eastern United States experiences a summer maximum of precipitation, Benton and Estoque found summer air crossing into the continent to be drier than air leaving the continent across the Atlantic Coast.[25] North America, in summer, moistens the air passing over it while, in winter, it dries the passing air.

*The cycling of impurities* into and out of the atmosphere is a budget of the interface which involves gases, liquids, and solids from natural and cultural systems. Study of the carbon, nitrogen, chlorine, and sulfur cycles illustrates that the atmosphere functions similarly in distributing impurities as it does in hauling these same materials in geochemical cycles. They also show that the hydrologic cycle and energy budget are instrumental in pollutant evolution and transport.

The cycling of particulate matter presents students with ideas that go beyond their common knowledge. The idea of a variable capacity of the atmosphere for particulates according to the convergence and divergence characteristics of air is a necessary foundation for the understanding of atmospheric pollution as a material budget in the atmosphere.

That atmospheric pollution is a negotiable question is a valid conclusion of the budget idea: polluting the atmosphere *is* easy. Pollution is achieved by: 1) setting the criterion of tolerable particulate or aerosol content at a low enough level so the material stored in the atmosphere on some days exceeds the criterion; 2) adding material to the atmosphere more rapidly than it is precipitated or diffused until the criterion of pollution is reached on certain days; 3) adding materials to the atmosphere whose chemical reaction products exceed tolerance levels for the materials produced by reactions.

Perhaps no textual treatment or lecture could assess the problems of the lower atmosphere so well as when students are asked to play the roles of mayor, federal commissioner, teamster union official, pensioner, industrialist, power-short public utility manager, automobile-dependent suburbanite, etc., under conditions of infrequently catastrophic and frequently tolerable but worsening calamities for which no simple technological solutions are anticipated. The causes for alarm and cooperation are then broadened beyond the physical process considerations.

*The composition of the atmosphere and its evolution* are unimportant as facts

[25] Benton, G. S. and M. Estoque, "Water-vapor Transfer over the North American Continent," *Journal of Meteorology*, Vol. 11, (1954), pp. 462–477.

but they serve two purposes which physical geography might exploit. First, the chemical quality of environment and the universal interaction of the internal and external forces of the earth at the interface are facilitated by tracing the evolving contest of volcanic emissions of gases, the escape of some gases from the atmosphere to space, and chemical reactions resulting in the "pollution" of the atmosphere by oxygen. Second, the role of the evolution of the atmosphere in the evolution of terrestrial life through transformations in the energy and materials budgets of the atmosphere can be presented as further evidence of the "systemness" of the environment through feedback processes among its component parts.

We suggest that the four topics discussed above, the energy budget, hydrologic cycle, cycles of impurities, and evolution of the atmosphere, deserve to be incorporated into the physical geography course because they embrace so well the ideas of work, systems, the interface as the primary locus of environmental work, and the efficacy of budgeting to elucidate the timing of the work of environment. Clearly, most other topics concerning the atmosphere that have been included in physical geography heretofore fail with respect to one or more of these criteria: either they bear no compelling relation to the work of the interface environment (e.g. jet streams) or they have been treated phenomenologically rather than as components of a working environment (e.g. air masses).

A similar analysis could be made of any of the other phenomena that are normally included in a physical geography course. Such an exercise either leads to their discard or to a reinterpretation of their place in physical geography. What remains in physical geography should enjoy a coherence which will not be manifest if encyclopedic inclusiveness is our only goal.

**Global Tectonics**

A topic with a great deal of current appeal is variously called continental drift, sea-floor spreading, and more recently "new global tectonics." Developments have been swift since electronic instruments revolutionized oceanography in the 1950's. Aggressive programs have brought forth a prodigious quantity of data in a brief period and at a bargain price—one of the greatest successes of science, ever.

The new global tectonics has made some extremely impressive demonstrations that the magnetic orientations of iron-rich minerals in igneous rocks constitute interpretable fossils of the earth's magnetic field at the time those minerals solidified. Furthermore, offset blocks of magnetized rock on the ocean floor generally can be accounted remarkably well by assuming the floors of the ocean are moving as very large plates of thin lithosphere resting on plastic materials at a shallow depth of about 100 km. beneath the earth's surface. Six plates are asserted to be sufficient to explain quite well the main movements of the present crust. Thin plates of rigid lithosphere are considered to be "created" along great linear ridges often occupying a central position in ocean basins. In opposite directions, plates slide away from the ridges by a steady motion and newly solidified rock materials progressively are added to the trailing edge of each plate. Far away, plates converge

along linear features and one or both plates plunge into the plastic zone beneath their convergence where remelting occurs. Island arcs, deep trenches, and volcanoes are a frequent feature of the convergence zone of plates.

Parallel conveyor belts have been suggested as a crude analogy for the places which emerge along the linear ridges usually in ocean basins, spread horizontally with their edges scraping adjacent, parallel conveyor plates and plunge along the line where an opposing plate is met.

The new global tectonics is a welcome explanation of many perplexing features of the structures of ocean basins and continents: the distribution of earthquakes and volcanoes fits the linear features where plates originate or disappear; the great linear fault features of ocean floors correspond to rips and tears in the "conveyor belt" plates; and cordillera systems are often located at convergences between plates. Acceptance of the scheme is new (mainly since 1964) and is supported especially by marine geologists more than by the continental variety.

Some complications are created or intensified by the scheme, mainly problems of continental and near continental areas. The Ozarks and the Urals are difficult to include; the geosynclines of continental margins and interiors are somewhat unemployed.

For physical geography, the topic presents some opportunities which possibly could enhance the approach we have adopted. First, is the simple matter that the interface of the lithosphere has a budget of "created" materials and plunging, disappearing materials; this budget comprises one of the powers of environment, and some interest exists in the rates of the budget elements. Second, there is a major segregation of rock materials, as between the dense "basic" minerals of the ocean floor rocks versus the "acidic" light-colored, low-density minerals in rocks of the continents. This distinction invites the hypothesis that some budgetary arrangement of light, continental materials may somehow be separate from or superimposed upon the conveyor belt arrangement of dense ocean-floor materials. The hydrologic cycle, operating on the acidic rocks to remove more iron and basic constituents, seems to have a possible role in furthering the contrasts between continental and oceanic rock materials. Third, are the related questions of how the rock cycle is powered and whether it is less energetic than the hydrologic cycle. The suggestion that the global tectonics system is dependent upon thermal convection beneath the lithosphere and gravitational sliding of plates away from the ridges leaves some difficult problems. One implication is that the rock cycle might have only a finite energy supply beneath the lithosphere which will be exhausted at some time. Then, continental denudation and isostasy still might continue to operate some kind of continental cycle of segregated minerals if the oceanic cycle were halted. A variation on this idea is that the energy of the region beneath the lithosphere is not finite but more or less permanent, is derived from the natural radioactivity of minerals whose renewal is assured by the budget of meteoritic additions to the earth system. If this dependence can be demonstrated, the resulting budget could be an interesting parallel to the solar energy budget of the earth; together they might comprise the two most basic driving forces in physical sciences.

Finally, we should point out that there are some extremely difficult assumptions of the model that convected material causes oceanic ridges to split always at the same place, plates are driven away rather rapidly from the oceanic ridges, plates traverse thousands of miles without apparently significant distortions such as folding or metamorphism and then plunge consistently beneath the margins of other plates with great seismic and volcanic stress. It is a tempting speculation to consider the possibility that the driving force for the rock cycle could be the hydrologic cycle, denuding the continents. If the eroded materials were deposited on the continental rises which might collapse as Dietz argues[26] and if the denuded areas rose, as isostasy demands, the resulting continental circulation would have a driving force of some durability and with a probable circulation-generating effect on the upper mantle. If this were the only circulation of the rock cycle, it might pull oceanic plates toward its descending limbs, incorporate the lighter minerals with the continental circulation, repeatedly split the ocean ridges in the same weak places, and, under tension, preserve the oceanic lithosphere plates from the crumpling which compressional forces seem to achieve on continents. These are raw speculations, unsupported by computations of rates of energy circulated; their purpose is to provoke exploration of the possibility that physical geography has but one cycle before all others and its name is Hydrologic!

**Viewing Resource Management in the Context of Environmental Work**

The budgetary approach for evaluating the timing, type, and sequence of work performed by environments offers the prospects of relating human management of resources more effectively to the operation of environments. With the environment conceived as a work system and the budgetary approach as a means for estimating the type, timing, and ultimately the amount of work performed, then management schemes and resource developments devised by men can be seen as attempts to alter either the type of work and/or its timing at any given place.

The interface environment is the home of man and the material resource of his existence. He has no choice but to manage his survival within its context. How he manages and the degree to which he manipulates and exploits physical environments varies greatly among societies of the earth. However, no matter how advanced or simple the technology, tools, and skills of a society may be, none can ignore the nature and timing of the work of the environment. This point has been made repeatedly through references to resource management implications of the operation of environmental systems. To illustrate this point further as well as to demonstrate the application of the proposed budgetary approach for evaluating the working environment, two sketches of human management of environment are presented.

The materials budgets of urbanized and traditional human systems show contrasts that raise questions about cultural differences in man's management of

[26] Dietz, Robert S., "Passive Continents, Spreading Sea Floors and Collapsing Continental Rises," *American Journal of Science*, Vol. 264, (March, 1964), pp. 177–193.

the working environment. The modernized, metropolitanized human system is sustained by an elaborate man-made transportation and communication network which reaches out and brings together resources from a diversity of environments literally from over the face of the earth. Nevertheless, the production of materials by humans to satisfy their desires gives these materials their form only temporarily, just as the materials of plant growth are only temporarily organized as a plant. The production stage must give way to the deterioration or decay stage. Thus, the increasing efficiency by which metropolitan centers are able to gather together and process environmental resources into more utilitarian material wealth requires similarly increasing efficiency for its dispersal or it becomes a problem of waste accumulation and disposal. So far, the elaboration of metropolitan spatial organization has been attended by few basic changes in the techniques of disposal. Burning, burying, or rinsing, essentially the medieval urban techniques, still predominate. By and large, cities concentrate their waste and dump it on the environment, still concentrated. The waste flow is not adjusted to the environment's seasonally changing and limited ability to process materials. Hence, in the context of environmental work available at the localities of metropolitan centers, one must conclude that cities have, as a minimum, created an imbalance in the spatial materials budget of the interface environment.[27]

In contrast to the metropolitan situation, the traditional agrarian form of human organization is primarily based on local resources of the environment for the material needs of the people. The primary means by which the environment of the locality is used to yield the material needs of existence is through the management of biological productivity. Management involves manipulation of locally available resources to enhance biological productivity, and there is very little importation of materials to supplement local resources. Use of exotic streams for irrigation water is the most likely exception to this principle. The basic problems, therefore, of this form of resource management is the local resource limitations for improving production in the biological system beyond that normal for the endowment of the local environment. Wastes in the traditional agrarian community are essentially biological and their decay is driven by the same processes that drive production. A locality under this form of human use should not have the imbalances that have created such a problem for modernized societies.

Questions of infrastructure of each system, contrasts between them, and lessons to be learned from each for the more efficient management of the other arise. While they may begin with all good intentions as "physical geography" they soon veer into no man's land between physical and human geography—which is precisely our intention. For example, concepts of the working environment provide students with the opportunity to consider alternatives to the flawed materials budgeting system technological societies have developed. Making closed systems of cities to recycle all its materials is a popular proposal, but this obviously can't work for the organic materials where the energy and moisture resources for growth and decay are

[27] Wolman, Abel, "The Metabolism of Cities," *Scientific American,* Vol. 213, (1965), pp. 178–190.

diffused over the landscape. What other possibilities are there, e.g. what is the relative area needed for primary production and decomposition, and how would such considerations call for changes throughout the technological society? Problem solving through simulation could bring an element of exciting discovery into physical geography classrooms.

The sequencing of human effort in environments with different work regimes points to the effect of environment in shaping choices for human activity. Major contrasts in human endeavor can be drawn among low work, high work, and seasonally high-low work environments.

The environments of low work are due either to dryness or lack of energy endowment (cold). In both cases, levels of biotic and chemical work as well as material translocational work are very low. Neither production nor decay can be very active. It is apparent that population could never be very large in areas of such environments if people must depend on local resources of the environment for biological production. However, bringing in outside resources or reorganizing available resources might open opportunities for larger numbers to thrive, especially in dry environments.

Irrigation is one such resource reorganization that is widely practiced. Irrigation makes it possible for the potential energy of these environments to be put to use for biologic activity. However, the chemical work which is activated by the new moisture conditions also sets in motion a sequence of changes in the soil system. Weathering of materials increases and products of weathering and imported nutrients begin to accumulate. The changed soil chemical and physical characters can produce undesirable effects on the crops grown. One response is increased irrigation to leach away the accumulating products of weathering and solubles in the water, but this can bring on rising water tables and further undesirable consequences. Because of these compounding problems with desert soil, irrigation that has succeeded over long periods of time on the same site is usually located on floodplains, deltas, and alluvial fans whose soils are likely to be composed of soil materials eroded from humid places and are more stable than indigenous soils under the conditions of irrigation.

In this light, it is tempting to conclude that the abundance of visible biological resources in environments with high energy and moisture endowments (humid tropical areas) is an attractive opportunity for human settlement. The standing stock of biomass in these areas is often large and the turnover of biomaterial has been found to be quite high. If one looks at the distribution of population in tropical areas, it is apparent that the lowest densities include areas where moisture income equals or exceeds potential evapotranspiration for all or nearly all months (the highest potential work environments). The Amazon and Congo basins are outstanding examples of such situations. Does this mean that mankind has overlooked an obvious opportunity, or do these environments pose major management problems in their use?

Attempts to use these seemingly rich biological circumstances by man, even with the employment of modern technology, have more often than not resulted in

failures. Some of those who have investigated this problem have laid most of the blame on poor soils. The high work performance of the environment has caused very active chemical decay at or near the surface, and the surpluses of moisture have resulted in excessive leaching of plant nutrients from the soil. But how can the abundance of biomass exist? The answer is to be found in the vegetation growth and decay cycle. As rapidly as dead bio-residue is broken down into constituent minerals under the high energy and moisture conditions, it is reabsorbed by the living biomass. As a result, the standing vegetation is living largely from itself with the highly weathered mineral soils needed primarily to anchor the plants. As a source of nutrients for growth, the soil is a poor provider and, unless the living stock of biomass is drastically depleted, nutrients from the inorganic solids are really not much needed.

With cultivation, the growth-decay cycle is disrupted and the husbanded plants must depend on nutrients from the soil which are not plentiful. The obvious question seems to be, why not overcome this condition by adding nutrients obtained from other places to the soils of these places? Though this is possible, it is not easily managed because the low capacity of highly weathered soils to retain ionic forms of minerals needed by plants means that wherever moisture surplus occurs frequently, as it does in these environments, leaching will remove nutrients nearly as fast as they are added. By comparison, the less weathered soils, that are much more common in other less active environments, have much greater capacities (cation exchange capacity) to retain nutrients in ionic form against the processes of leaching. Fertilization practices need to be adjusted to these storage conditions. A logical design would be to add a little fertilizer frequently, but such frequent applications pose difficulties in procedure and costs.

Another possible reason for the seemingly poor opportunities for human existence in the year-round higher work environments is that decay and production are continuously occurring and at about equal rates at all times. In order for man to obtain production under these circumstances, he must organize to gather the constant flow of product before the competition from other continually working organisms and decay consumes it. Moreover, the management of those plants preferred by man is complicated by the constant presence of predator organisms that may attack plants prior to their reaching the stage most useful to man.

By comparison with the situation in year-round high work environments, management of agriculture in the environments with seasonal changes in work performed has been much more effective in yielding biological products for human use. The sequencing cycle imposed on biological processes and materials by environments of seasonal work consists of a production phase, a dormant or storage phase, and a decay phase, with the latter being simultaneous with the production phase of the next cycle. Products of the growing season mature more or less simultaneously, usually just about the time the dormant season sets in. This is very convenient for human use because the product is available without much competition from other organisms or chemical decay since these activities have been rendered more or less dormant by the environment. Man processes them

through his system before they are subject to attack during the following growing season.

Moreover, the sequence in environmental work probably makes management easy in that man can specialize his activities to those of the season; there is a time to plant, a time to cultivate and protect crops, a time to harvest, and a time to rest and get renewed for the cycle to be repeated. In the year-round high work environments, there is no such sequencing. All of these activities must be managed simultaneously. Could this be a plausible reason for some of the material successes of people in the environments where biological work in particular is strongly seasonal and quite high?

Whether, in fact, the environments of seasonal work offer humans an easier context in which to manage increased biological output than is possible in the environments which are constantly active is only suggested, not confirmed. However, it is intriguing to consider that the budget of work of environments may be, in some way, fundamental to understanding the potential for certain forms of human management, in particular, crop agriculture. It also suggests that successful resource management organizations developed under one environmental economy may be quite inappropriate when applied in different environmental work economies.

The seasonality of human activities in different environments is a part of the lore of geography. It has been expressed as a relation between the seasonality of precipitation or temperature, and that of native cultures. The various work regimes in low, high, and seasonal work environments suggest the intricacy of interaction between resources management procedures and the operations of natural systems, and raise the question as to whether an understanding of this isn't the ultimate goal for physical geography. The interactions range from fundamental to incidental, world-wide to microcosmic. They can be uncovered in a coordinated effort by a class, or as serendipities by a student whose systems orientation permits him to see the implications of the operation of environmental systems for the human systems with which he is concerned. In either case, it will become apparent to the student that the schism between human and physical geography is a product of arbitrary focus, not of the way human and natural systems operate separately and in interaction.

## CHAPTER V

# ADVANTAGES OF THE INTERFACE APPROACH OVER THE TRADITIONAL PHYSICAL GEOGRAPHY

The intent of the previous section is to challenge the traditional physical geography course, to offer an alternative based on the work of the interface region and to list some of the points of contrast the suggested alternative can bring to the beginning course. The traditional physical geography course was found wanting with respect to three criteria which might be taken as a basis for evaluating the merits of courses, viz., 1) a unifying internal theme and methodology; 2) a clear functional articulation with the rest of the discipline and the questions it addresses, and 3) a pedagogic approach that directs the learner toward new questions and their effective exploration.

The proposed alternative physical geography consists of a focus on work in environmental systems at the interface, and it has a splended coherence of its topics since all topics are acquired as illustrations of the focus. Moreover, there is but one basic paradigm now available for converting the data of the energy and moisture endowments into parameters which are associated with virtually all the work processes in environmental systems. Methodologically, the computational model to find the quantities of water which are effective for different work processes provides a unity of procedure.

The alternative physical geography proposed here has some advantages over the traditional for implementation by the entire field of geography. A work focus can provide information on current and future processes and their probable work events to which management objectives and policies must be addressed. The work focus requires us to make a determination about the physical conditions of places, acknowledging the different results that might be the consequence of different ways in which the land is utilized. Such a focus announces that the physical environment is not merely a fixed background or stage upon which a vital drama of human concerns is enacted; instead, the physical environment is powerfully endowed with energy so it will march through its own scenario unless some other directions are given to it; importantly, it cannot be stopped from taking some course. It would seem this view of environment might penetrate every responsible geographic study of the man/land theme unless it can be demonstrated that the environment is inert, accomplishing nothing, and its work is not affected by, nor effective for, the particular activities of man in a certain study. This focus does not lend itself to the grand generalizations such as many classifications provide. "The setting" which appears in so many papers as the summary of physical environmental facts, must now be considered with suspicion as a probable attempt to eject

the environment from studies without a consideration of environmental work. So directly does the environmental work approach articulate with the man/land theme and so conveniently does it offer a calendar of work progress that it invites physical geography to include man's use of the land as a consistent theme to be evaluated in terms of altered work by environment and the purposes which might justify such changes.

The interface approach to physical geography seems to offer an utter contrast with the traditional approach in respect to the role played by the application of topics to further learning. The interface approach has a definite focus, but there is no finite, approved knowledge to which the student must demonstrate he is privy or qualified to repeat it. Instead, the need for inquiry by the interface approach is genuine, and there are many environmental problems continually evolving for which the student is experienced as a result of the course and which he can probe for his own purposes. Because the water budget model is so widely applicable to translating data of the thermal and moisture endowments into forms which are essential to work and because it provides a means for reasoning about the effective moisture and energy for different kinds of environmental work, it lends itself to gratifying the need of the persistently challenged mind for a model to learn by long after the classroom experience has blurred. The critical point upon which to contrast the two approaches most effectively probably is the way the water budget itself is involved in each approach. In the traditional approach it is an isolated object to understand as a bookkeeping procedure and it contains four or five underlined terms with enormous numbers of syllables. In the proposed interface approach, the water budget is not an objective but a tool for allocating water to the forms in which it is associated with energy in the work of systems. The water budget's components must be justified by the user so this reasoning procedure ensures he must embrace some model of how work probably is done. Opportunities for comparing postulated and real results are thereby created. "Knowing" is certainly a part of the interface procedure but it must be constrained at the outset by the much greater urgency of "learning how to learn"; yet, it is almost limitless how much "knowing" can come to the student *as a result* of his application of the principles and tools which the interface approach provides.

If the arguments and examples thus far have persuaded anyone to look critically at our tradition or to find merit in the prospect of an alternative physical geography, our purpose is largely fulfilled. Now, we come to some implications of the foregoing which might affect the usual ways physical geography is regarded by the profession and by physical geographers. The first of these concerns the possibility that any approach which could change the goals of the physical geography's course might alter the role played by the field of physical geography in the profession. Could a unified physical geography course presage the development of a profession of physical geography? Our premise is that a discipline of physical geography does not now exist. If one endeavors to identify the present field of physical geography by positive criteria, then the study of environment, or some similarly broad objective, is embraced. One difficulty for any profession so defined

is that the contribution, compared to the broad needs, must be utterly miniscule, while the effort to maintain contact with contributions by other overlapping disciplines is Herculean. Yet, a broad sweep of topics must be included in order to embrace the interests possessed by presently practicing physical geographers. The argument can be made that each of those who admits the label of physical geography is a specialist who naturally lacks comparable depth of knowledge in several other systems comprising environment. Consequently, no individual is a physical geographer, *per se* and no profession of positive integrating ideas exists. Each specialist has more sophistication in common with others in the particular physical science which parallels his interest in geography (meteorology, climate, geomorphology, soils, ecology, hydrology, etc.,) than with physical geographers of some different stripe. Each has little need for the taxonomy or the sophisticated information of alien physical geography specialists. Communication tends to be on fairly narrow interests. The present field of physical geography rests uneasily on this foundation.

Most physical geographers must take note of the work dimension in their area of interest, but they make little effort to articulate the progress of work through time in processes with which they deal. However, if a significant number of physical geographers did address themselves to reporting work accomplishments of the systems which they prefer to investigate, the information might suffice to transform these presently federated interests into a union of interest. That is to say, a unifying discipline—in addition to the existing, more specialized interests—could emerge. The mission of the discipline might be to assess how all natural events of places were interrelated by sharing the environment's resources for doing work. The scope of questions hardly could exclude man's functioning.

Although this approach does not necessarily rule out the traditional encyclopedic interest in identifying *things* in the landscape nor their distributions, it does suggest that physical geographers could be of service for the solution of some kinds of environmental problems. They would have to provide data on the work accomplishments of environment which, as yet, are largely not compared. This approach also promises that physical geographers could be more unified and possibly more helpful to one another concerning the timing of environmental accomplishment and the frequency, amount, or proportional share that various processes have in the energy and material streams at the interface.

If the beginning course were integrated by the concepts of budgeting work at the interface, and an incipient professional geography emphasized research on the allocations of work in systems, the profession might feed examples and data to the course while the course might start students toward the obvious tasks.

If physical geography were concerned first with the work of environment and secondarily with other special interests, there should be some desirable options in this arrangement for the economic, cultural, etc., geographer whose topics embrace the man/land theme. Regional and human geographers should find the work concept a device by which environmental accomplishments can be incorporated consistently in their endeavors in a way other than the "physical setting." The

coincidence, or its lack, between regimes of environmental work and the calendar of human activities would seem to supply a solid basis for studies of the wisdom of how man has used his environment. An important implication is that *any* geographer–physical, human, etc.,–should find room to work in such questions which have been largely regarded as "cultural" or "historical" but often could benefit from more sophistication of how and when soil moisture, runoff, soil chemistry, growth, decomposition, or other dynamics of the working environment are manifested in relation to man's convenience, management, security, social institutions, and his notably dependent, seasonal activities.

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